[Title of Document] Specification

[Title of Invention] VEHICLE STEERING CONTROL APPARATUS

[Scope of the Invention]

[Claim 1] A vehicle steering control apparatus including: a plurality of electric motors having substantially the same performance, the electric motors being arranged integrally and coaxially on steered wheels of a vehicle steering mechanism; and a plurality of systems each including control means for controlling the associated electric motor, wherein the electric motors of the systems are simultaneously controlled to drive the steering mechanism common to the motors, the steering control apparatus being characterized in that:

the control means of one of the systems:

generating a first torque command required for driving the steering mechanism based on the steering position of a steering wheel and position information of the electric motor associated with the one of the systems; distributing the first torque command in accordance with the number of the systems; and controlling the torque of the associated one of the electric motors in accordance with the torque command distributed to the one of the systems, and

wherein the control means of other systems:

executing torque control relative to the electric motor of the associated system in accordance with the torque command distributed to the associated system.

[Claim 2] The apparatus according to claim 1, characterized by:

impairment detecting means for detecting impairment of each of the systems, wherein, when one or more of the systems, including the system generating the first torque command, are impaired, one of the control means of other normal systems: generates a second torque command required for driving the steering mechanism based on the steering position of the steering wheel and position information of the electric motor of the associated system;

distributes the second torque command in accordance with the number of the remaining normal systems; and controls the torque of the associated one of the electric motors in accordance with the torque command distributed to the associated system, and

wherein the control means of the other normal systems:

executes torque control relative to the electric motor of the associated system in accordance with the torque command distributed to the associated system.

[Claim 3] The apparatus according to claim 1, characterized by:

impairment detecting means for detecting impairment of each of the systems, wherein, when one or more of the systems, excluding the system generating the first torque command, are impaired, the control means of the system generating the first torque command redistributes the first torque command in accordance with the number of the remaining normal systems, and executes torque control relative to the electric motor in accordance with the torque command distributed to the associated system, and

wherein the control means of the other normal systems:

executes torque control relative to the electric motor of the associated system in accordance with the torque command distributed to the associated system.

[Claim 4] The apparatus according to claim 2 or 3, characterized in that,

the torque control includes current control for feedback controlling current of the electric motors, and

wherein the control means of each system has a different current loop gain for the current control when all the systems are functioning normally and when one or more of the systems is impaired.

[Detailed Description of the Invention]

[0001]

[Industrial Field of Application]

The present invention relates to a vehicle steering control apparatus used in a steer-by-wire type steering control apparatus and an electric power steering control apparatus.

[0002]

[Prior Art]

As a vehicle steering control apparatus that controls steered wheels of a vehicle, a steer-by-wire type steering control apparatus is known in the prior art. In a steer-by-wire type steering control apparatus, the steering wheel is not mechanically connected to a steering gear box, which is connected to the front wheels (steered wheels).

[0003]

In such a steering control apparatus, the steering wheel is not directly connected to the steering gear box and the steering angle of the steering wheel is detected. In accordance with the detected steering angle, the steering gear box is driven via an electric motor.

[0004]

This type of a steering control apparatus has a back-up system so as to reliably continue steering operation even when a breakdown occurs.

As the back-up system, for example, a configuration provided with two redundant systems has been proposed (see patent document 1).

[0005]

One of the systems is a primary system. The primary system includes an electric motor for driving a shaft coupled to the steered wheels, a drive circuit for driving the electric motor, a control circuit for driving the electric motor via the drive circuit, and various types of sensors necessary for controls. The other one of the control systems is a secondary system. The structure of the secondary system is identical to that of the primary system.

[0006]

In the apparatus provided with two systems, when both systems are operating normally, the systems operate the respective motors simultaneously to avoid mutual interference, and the electric motor of the primary system drives the shaft in accordance with the steering angle of the steering wheel.

[0007]

When the primary system is impaired, the electric motor is stopped, and the electric motor of the remaining secondary system drives the shaft.

[0008]

In patent document 2, a steering mechanism has been proposed in which a pair of steering motors are arranged at different positions and the steering mechanism distributes steering force necessary for steering at a predetermined ratio.

[0009]

[Patent Document 1]

Japanese Laid-Open Patent Publication No. 2002-37112 (Fig. 1, paragraphs [0015] to [0028])

[Patent Document 2]

Japanese Laid-Open Patent Publication No. 10-218000

[0010]

[Problems that the Invention is to solve]

As for the control system of the electric motors, the positions of the electric motors are controlled based on a detection value from a steering angle sensor for detecting the steering angle of a steering wheel. Thus, when simultaneously driving a plurality of electric motors, the motor torques may cause interference problems.

[0011]

For example, when performing a position feedback control based on the rotation angles of the electric motors detected by rotational angle sensors provided on the electric motors, the electric motors are controlled at mutually different positions due to electric motor assembly errors and rotation angle sensor assembly errors. Therefore, the generated torque

directions are mismatched, and the torque is reduced. Furthermore, noise and vibration are generated, and the electric motors are heated.

[0012]

In the art of patent document 1, a mutual interference detection mechanism is provided at a position where mutual interference occurs to avoid mutual interference caused by control errors of both systems. When the mutual interference detection mechanism detects mutual interference, the operation of one of the systems (including the operation of the electric motor) is stopped.

[0013]

When interference of the motor torques occurs, one of the systems may be stopped in the same manner as when mutual interference occurs due to control errors.

However, in this control method, the operation of one control system is stopped and the shaft coupled to the steered wheels is driven only by the remaining electric motor, even though both control systems were operating normally. Therefore, this method is undesirable when both control systems are operating normally.

[0014]

In the art of patent document 2, a pair of steering motors (a primary steering motor and a secondary steering motor) are arranged at different locations. Therefore, the art is based on the premise that the motor shape and configuration differ between the primary steering motor and the secondary steering motor.

[0015]

Since the performance of the motors (motor characteristics) is not uniform, the torque is only distributed at a predetermined ratio. Furthermore, a difference occurs in the performance before and after impairment occurs depending on which motor is impaired.

[0016]

It is an object of the present invention to provide a vehicle steering control apparatus capable of suppressing generation of noise, vibration, and heat without decreasing torque by solving a problem of torque interference between electric motors of systems when simultaneously operating the electric motors.

[0017]

Another object of the present invention is to provide a vehicle steering control apparatus in which no restriction is caused due to difference in the performance between the motors thereby facilitating torque distribution when an impairment occurs, and thus preventing a reduction in performance.

[0018]

[Means for Solving the Problems]

To solve the above problems, the invention as set forth in claim 1 provides a vehicle steering control apparatus including: a plurality of electric motors having substantially the same performance, the electric motors being arranged integrally and coaxially on steered wheels of a vehicle steering mechanism; and a plurality of systems each including control means for controlling the associated electric motor. The electric motors of the systems are simultaneously controlled to drive the steering mechanism common to the motors. The steering control apparatus is characterized in that the control means of one of the systems: generates a first torque command required for driving the steering mechanism based on the steering position of a steering wheel and position information of the electric motor associated with the one of the systems; distributes the first torque command in accordance with the number of the systems; and controls the torque of the associated one of the electric motors in accordance with the torque command distributed to the one of the systems. The control means of other systems execute torque control relative to the electric motor of the associated system in accordance with the torque command

distributed to the associated system.

[0019]

The invention as set forth in claim 2 provides the apparatus according to claim 1, characterized by impairment detecting means for detecting impairment of each of the systems. When one or more of the systems, including the system generating the first torque command, are impaired, one of the control means of other normal systems: generates a second torque command required for driving the steering mechanism based on the steering position of the steering wheel and position information of the electric motor of the associated system; distributes the second torque command in accordance with the number of the remaining normal systems; and controls the torque of the associated one of the electric motors in accordance with the torque command distributed to the associated system. The control means of the other normal systems executes torque control relative to the electric motor of the associated system in accordance with the torque command distributed to the associated system.

[0020]

In this specification, the phrase "distributes the second torque command in accordance with the number of the remaining normal systems" includes a situation in which, in a case where the steering control apparatus includes two systems, when the system generating the first torque command is impaired, the second torque command generated by the remaining normal system is used only by the remaining normal system.

[0021]

The invention as set forth in claim 3 provides the apparatus according to claim 1, characterized by impairment detecting means for detecting impairment of each of the systems. When one or more of the systems, excluding the system generating the first torque command, are impaired, the control means of the system generating the first torque command redistributes the first torque command in accordance

with the number of the remaining normal systems, and executes torque control relative to the electric motor in accordance with the torque command distributed to the associated system. The control means of the other normal systems executes torque control relative to the electric motor of the associated system in accordance with the torque command distributed to the associated system.

[0022]

In this specification, the phrase "redistribute the first torque command in accordance with the number of the remaining normal systems" includes a case in which when only the system that generates the first torque command is normal and other systems are all impaired, the generated first torque command is only used in the associated system.

[0023]

The apparatus according to claim 2 or 3, characterized in that the torque control includes current control for feedback controlling current of the electric motors. The control means of each system has a different current loop gain for the current control when all the systems are functioning normally and when one or more of the systems is impaired.

[0024]

[Embodiments]

A vehicle-mounted steer-by-wire type steering control apparatus (hereinafter, simply referred to as a steering control apparatus) according to one embodiment of the present invention will now be discussed with reference to Figs. 1 to 8.

[0025]

Fig. 1 is a schematic view showing a steering control apparatus according to the preferred embodiment.

The steering control apparatus is provided with an operating mechanism 100 including a steering wheel 10, a steering mechanism 200, which is a vehicle steering mechanism in this embodiment, and a control section 300.

[0026]

(Operating Mechanism 100)

The steering wheel 10 of the operating mechanism 100 is coupled to a rotary shaft 11 supported so as to be rotatable relative to the vehicle, which is not shown.

[0027]

A first steering angle sensor 14 and a second steering angle sensor 15 for detecting the steering angle of the steering wheel 10 corresponding to the rotational angle of the rotary shaft 11 are provided on the rotary shaft 11.

[0028]

The first steering angle sensor 14 is connected to a first ECU 21 of a first system SY1. The second steering angle sensor 15 is connected to a second ECU 22 of a second system SY2.

[0029]

(Steering Mechanism 200)

The steering mechanism 200 will now be described with reference to Fig. 2. Fig. 2 is an enlarged partial view showing the steering mechanism 200 of the steering control apparatus.

[0030]

A tube-like first shaft housing 30, a tube-like second shaft housing 31, and a tube-like motor housing 32 are connected to each other so as to have the same axis and are attached to a vehicle body (not shown). That is, the motor housing 32 is connected to the rack housings by bolts 33 and 34 (see Fig. 2).

[0031]

A shaft 35 is accommodated within the tube-like housing configured by the first shaft housing 30, the second shaft housing 31, and the motor housing 32 so as to be non-rotatable but movable in the longitudinal direction. The two ends of the shaft 35 are each mechanically connected to the left and right front tires T (steered wheels) by a tie rod. The motor housing 32 also functions as a housing of the steering

mechanism 200.

[0032]

Next, the configuration inside the motor housing 32 will be described with reference to Figs. 2 and 3.

A pair of motors (electric motors) are accommodated within the motor housing 32. Hereinafter, the motors are referred to as a first motor 36 and a second motor 37 and the motors are desirably three-phase synchronous-type brushless DC motors.

[0033]

The first motor 36 and the second motor 37 have a stator 38, which configures a common stator, and a motor shaft 39, which configures a common rotor. Accordingly, the motors are arranged coaxially.

[0034]

The stator 38 includes a plurality of salient poles 40 which fit into the inner circumference of the motor housing 32, and the plurality of salient poles 40 are provided at equiangular intervals. In the present embodiment, twelve salient poles 40 are provided. Mounted on each salient pole 40 is an insulating bobbin 44 on which is wound a first motor coil 41 corresponding to the first motor 36 and a second motor coil 42 corresponding to the second motor 37. In the present embodiment, the first motor coil 41 is arranged closer to the motor housing 32 on the salient pole 40, and the second motor coil 42 is arranged closer to the motor shaft 39 on the salient pole 40 (see Fig. 3).

[0035]

The first motor coil 41 and the second motor coil 42 are coated with an insulating resin layer formed by molding.

In the preferred embodiment, the first motor coil 41 and the second motor coil 42 are wound about each salient pole 40 such that each salient pole 40 has the same phase and polarity. The first motor coil 41 and the second motor coil 42 are respectively controlled by a first drive circuit 55 and a

second drive circuit 57.

[0036]

For example, a second motor coil 42 having a U-phase is wound on a salient pole 40, on which a first motor coil 41 having a U-phase is wound. A second motor coil 42 having a V-phase is wound on a salient pole 40, on which a first motor coil 41 having a V-phase is wound. A second motor coil 42 having a W-phase is wound on a salient pole 40, on which a first motor coil 41 having a W-phase is wound. Similarly, a plurality of second motor coils 42, which respectively have a /U-phase, a /V-phase, and a /W-phase, are wound on a plurality of salient poles 40 provided with a plurality of first motor coils 41, respectively having /U-phase, /V-phase, and /W-phase. The phases with the attached forward slash symbol "/" and the phases without the slash symbol "/" indicate that the coil directions are opposite so as to produce salient poles 40 of opposite polarity. In the following description, coils which have a U-phase and /U-phase are simply referred to as U-phase coils. The coils having other phases are similarly referred to as "-phase coils".

[0037]

The coils on each salient pole 40 are arranged in the motor rotation direction in the sequence: U1, /U1, V1, /V1, W1, /W1, U2, /U2, V2, /V2, W2, /W2. U1 and U2 are U-phases which have mutually identical polarities, and /U1 and /U2 are U-phases which have mutually identical polarities. V and W are similar.

[0038]

The outputs of the first motor 36 and the second motor 37 are mutually identical. That is, in the present embodiment, in order to equalize the outputs of both motors, the same number of first motor coils 41 and second motor coils 42 are provided on each salient pole 40, and excitation currents of identical magnitude are output from the drive circuit 55 and the second drive circuit 57. That is, the first ECU 21 and

the second ECU 22 control the excitation currents output from the first drive circuit 55 and the second drive circuit 57 to be equal. Accordingly, when both motors are operating simultaneously, their synthesized output torque is double the output torque of the individual motors.

[0039]

The first drive circuit 55 corresponds to a first drive means and the second drive circuit 57 corresponds to a second drive means.

The motor shaft 39 is a hollow tube, arranged coaxially on the exterior side of the shaft 35 in the middle part in the longitudinal direction of the shaft 35. One end of the motor shaft 39 is supported by the motor housing 32 and the first shaft housing 30 via a first bearing 45.

[0040]

A hollow cylinder-like nut retainer 47 is formed on the other end of the motor shaft 39. The diameter of the nut retainer 47 is larger than the diameter of the middle part of the motor shaft 39. The nut retainer 47 is supported by the motor housing 32 and the second shaft housing 31 via a second bearing 46 so as to be rotatable about its own axis.

[0041]

Accordingly, the motor shaft 39 is supported by the first and second bearings 45 and 46 so as to be rotatable relative to the first and second shaft housings 30 and 31 and the motor housing 32.

[0042]

A permanent magnet 48 is attached on the exterior surface of the motor shaft 39 at a position opposite the stator 38, which is located at the axially middle part of the motor shaft 39, to be rotatable integrally with the motor shaft 39. When current is supplied to at least one of the first motor coil 41 and the second motor coil 42 of the stator 38, rotational force with its central axis located at the axis of the motor shaft 39 is generated on the motor shaft 39 provided with the

permanent magnet 48, and the motor shaft 39 is rotated.

[0043]

A ball screw nut 49 is attached coaxially to the motor shaft 39 on the interior surface of the nut retainer 47. The ball screw nut 49 has a helical ball screw channel 50 formed on its interior surface.

[0044]

The shaft 35 has a helical ball screw channel 51 formed in a predetermined range in the longitudinal direction on its exterior surface. A plurality of balls (not shown) are rotatably accommodated between the ball screw channel 51 and the ball screw channel 50. A ball screw mechanism provided with a bal screw structure is formed by the ball screw channel 51 of the shaft 35 and the ball screw nut 49.

[0045]

The ball screw mechanism converts the output torque of the normal and reverse rotation of the motor shaft 39 to thrust of a reciprocal motion of the shaft 35 in the longitudinal direction.

A first rotation angle sensor 52 and a second rotation angle sensor 53 are arranged so as to be mutually adjacent between the stator 38 and the first bearing 45 of the motors in the longitudinal direction of the motor shaft 39. The first rotation angle sensor 52 and the second rotation angle sensor 53 are configured by rotary encoders.

[0046]

The rotation angle sensors supply two-phase pulse train signals, which differ by $\pi/2$, and zero-phase pulse train signals representing the standard rotation position in accordance with the rotation of the motor shaft 39 to the first ECU 21 and the second ECU 22. In the following description, signals detected by and output from each rotation angle sensor are simply referred to as detection signals (including the two-phase pulse train signals and zero-phase pulse train signals).

[0047]

The detection signals from the first rotation angle sensor 52 and the second rotation angle sensor 53 are supplied to the first ECU 21 and the second ECU 22 at predetermined sampling periods.

The first ECU 21 and the second ECU 22 determine the rotation angle of the motor shaft 39 of the first motor 36 and the second motor 37 relative to the stator 38 based on the received detection signals.

[0048]

(Control Section 300)

The control section 300 is described below.

The control section 300 is provided with a first ECU 21, a second ECU 22, a first drive circuit 55, and a second drive circuit 57.

[0049]

The first ECU 21 and the second ECU 22 are each configured by an electronic control unit, which includes a microcomputer.

1. First ECU 21

The first ECU 21 has various functions such as calculation functions, processing functions, and memory functions performed by control programs. That is, as shown in Fig. 5, the first ECU 21 includes a position controller 21A, a torque distributor 21B, and a current controller 21C.

[0050]

The control modes of the first ECU 21 include a start control mode and a normal control mode.

(Start Control Mode and Normal Control Mode of First ECU 21)

In the start control mode and the normal control mode, the first ECU 21 executes the steering control of the first motor 36 via the first drive circuit 55 so as to obtain the turning angle (turning angle of the steered wheels) corresponding to the steering angle detected by the first

steering angle sensor 14, and so as to generate the thrust required for the motor shaft 39 for that purpose.

[0051]

Specifically, the position controller 21A receives the steering angle detected by the first steering angle sensor 14 as a position command. Furthermore, the position controller 21A receives a detection signal from the first rotation angle sensor 52, and calculates the rotation angle of the motor shaft 39 relative to the stator 38 based on this detection signal. The detection signal of the first rotation angle sensor 52 includes position information of the electric motor.

[0052]

The position controller 21A calculates the difference between the calculated rotation angle of the electric motor (first motor 36) and the steering position based on the steering angle which is the position command. The position controller 21A multiplies this difference by a predetermined gain required for the position control, and supplies this multiplication value to the torque distributor 21B as a torque command ΔP.

[0053]

The torque command ΔP corresponds to a first torque command generated based on a computation result of the position control.

The position controller 21A controls the position feedback such that the difference between the command value (position command) and the feedback value (rotation angle of the first motor 36) is zero.

[0054]

The torque distributor 21B distributes the supplied torque command ΔP by a predetermined distribution ratio and respectively supplies the divided torque commands $\Delta P1$ and $\Delta P2$ to the current controller 21C of the first system SY1 and the current controller 22C of the second system SY2.

[0055]

When both systems included in the steering control apparatus are normal, it is desirable that the torque distributor 21B changes the distribution ratio such that the distribution ratio when starting the engine of the vehicle is different from the distribution ratio at times other than when starting the engine.

[0056]

In the present embodiment, when starting the engine of the vehicle (in the start control mode), the distribution ratio is 50:0 (= $\Delta P1:\Delta P2$), and at times other than when starting the engine (in the normal control mode), the distribution ratio is 50:50 (=$\Delta P1:\Delta P2$).

[0057]

The steering control of the first motor 36 executed by the first ECU 21 includes position control for controlling the turning angle in accordance with the steering angle, and torque control for obtaining a thrust required for the motor shaft 39, or for obtaining the output torque.

[0058]

Fig. 6 is a control block diagram of a current controller 21C.

The current controller 21C includes a torque current converter 61, PI controller 64, PI controller 65, a d/q inverter 66, a pulse width modulator (PWM) 67, a d/q converter 68, and an angle detector 69.

[0059]

In the normal control mode, the current controller 21C receives a torque command $\Delta P1$, a detection signal of the first rotation angle sensor 52, and current detection signals relating to two excitation currents iu and iv among the three-phase excitation currents iu, iv, and iw of the first motor 36 supplied from the current sensors 71 and 72 described below.

[0060]

The angle detector 69 calculates the rotation angle θ based on the detection signal of the first rotation angle

sensor 52 and supplies the rotation angle θ to the d/q converter 68.

The d/q converter 68 is provided with the excitation current iw (current detection signal) calculated by a calculator 70 based on the excitation currents iu and iv.

[0061]

The excitation currents iu, iv, and iw are excitation currents actually supplied to the first motor 36.

The d/q converter 68 subjects the current detection signals to d/q conversion using the rotation angle θ so as to generate current values id and iq.

[0062]

The d/q conversion is a well-known method for converting an alternating current to a direct current by mapping the vectors of the alternating current of each phase in a coordinate system in which a direction identical to the magnetic flux of the electric motor rotor is designated the d-axis, and a direction perpendicular to the d-axis is designated the q-axis.

[0063]

The torque current converter 61 converts the torque command ΔP1 to a q-axis current command value iq*. The deviation calculator 63 calculates the difference ΔIq between the q-axis command value iq* and the current value iq from the d/q converter 68.

[0064]

The deviation calculator 62 calculates the difference ΔId between the d-axis current command value id* and the current value id from the d/q converter 68. In the brushless DC motor, the rotor is a magnet, and excitation current is unnecessary. Accordingly, the d-axis current command value id* is zero.

[0065]

The PI controller 64 receives the difference ΔId and performs the proportional and integral action of the difference ΔId, and calculates a d-axis voltage command value

Vd* using a voltage equation. The PI controller 65 receives the difference ΔIq and calculates proportional integrals of the difference ΔIq, and calculates a q-axis voltage command value Vq* using a voltage equation.

[0066]

The d/q inverter 66 receives the d-axis voltage command value Vd* and the q-axis voltage command value Vq*, and calculates voltage command values Vu*, Vv*, and Vw*. The pulse width modulator 67 receives the voltage command values Vu*, Vv*, and Vw*, and supplies pulse signals (PWM control signals) having pulse widths respectively corresponding to the voltage command values Vu*, Vv*, and Vw* to the first drive circuit 55. The first drive circuit 55 applies drive voltages for each phase of the first motor 36 in accordance with the pulse signals (PWM control signals).

[0067]

In this way, the current controller 21C controls the current feedback (hereinafter, referred to as current feedback control) such that the difference between the command value (torque command ΔP1) and the feedback value (current value iq and current value id of the first motor 36) is zero.

[0068]

The current control is equivalent to the torque control.

(At Failure of First System SY1)

When the first system SY1 is impaired, the first ECU 21 of the first system SY1 stops the control of the first motor 36, as shown in Fig. 7.

[0069]

2. Second ECU 22

The second ECU 22 is a microcomputer having calculation functions, processing functions, and memory functions, and having a start control mode, normal control mode, and failure control mode.

[0070]

The second ECU 22 includes a current controller 22C in a

start control mode and a normal control mode as shown in Fig. 5, and a position controller 22A and current controller 22C in an failure control mode as shown in Fig. 7.

[0071]

(Start Control Mode and Normal Control Mode of Second ECU 22)

In the start control mode and normal control mode, the current controller 22C receives a torque command ΔP2, a detection signal of the second rotation angle sensor 53, and current detection signals relating to the two excitation currents iu and iv among the three-phase excitation currents iu, iv, and iw of the second motor 37 supplied from the current sensors 71 and 72, which will be described below, as shown in Fig. 5.

[0072]

Like the current controller 21C shown in Fig. 6, the current controller 22C includes a torque current converter, a pair of PI controllers, a d/q inverter, a pulse width modulator, a d/q converter, and an angle detector.

[0073]

The structure of the current controller 22C in the normal control mode is identical to that of the current controller 21C. The same reference numerals are given to those components that are like or the same as the corresponding components of the current controller 21C shown in Fig. 6 and explanations are omitted.

[0074]

In the same manner as the various parts of the current controller 21C, the various parts of the current controller 22C process the torque command ΔP2, detection signal of the second rotation angle sensor 53, and current detection signals relating to the excitation currents iu and iv supplied from the current sensors 71 and 72, which will be described below. The pulse signals (PWM control signals) generated by this processing are supplied from the second ECU 22 to the second

drive circuit 57. The second drive circuit 57 applies a drive voltage generated in accordance with the pulse signals (PWM control signals) to each phase of the second motor 37.

[0075]

As described above, the current controller 22C controls current feedback such that the difference between the command value (torque command ΔP2) and the feedback value (current value iq and current value id of the second motor 37) is zero.

[0076]

The current control is equivalent to the torque control.

In the start control mode, since the torque distributor 21B sets the distribution ratio to 50:0 (=ΔP1:ΔP2), the torque command ΔP2 supplied to the current controller 22C is zero. Accordingly, the second motor 37 is not actually driven by the second ECU 22.

[0077]

(Failure Control Mode of Second ECU 22)

In the failure control mode, the steering control of the second motor 37 executed by the second ECU 22 includes position control for controlling the turning angle in accordance with the steering angle, and torque control for obtaining a thrust required for the motor shaft 39, or an output torque.

[0078]

In the failure control mode, the second ECU 22 executes the steering control of the second motor 37 via the second drive circuit 57 so as to have the turning angle (the turning angle of the steered wheels) correspond to the steering angle detected by the second steering angle sensor 15, or to obtain the thrust required for the motor shaft 39 for that purpose.

[0079]

Specifically, the position controller 22A receives the steering angle detected by the second steering angle sensor 15 as a position command. Furthermore, the position controller 22A receives a detection signal from the second rotation angle

sensor 53, and calculates the rotation angle of the motor shaft 39 relative to the stator 38 based on this detection signal.

[0080]

The detection signal from the second rotation angle sensor 53 corresponds to position information of the second motor 37 (electric motor).

The position controller 22A calculates the difference between the calculated rotation angle of the electric motor (second motor 37) and the steering position based on the steering angle, which is the position command. The position controller 22A multiplies this difference by a predetermined gain required for the position control, and supplies this multiplication value to the torque distributor 22C as a torque command ΔP3.

[0081]

The torque command ΔP3 is equivalent to a second torque command.

The position controller 22A executes position control such that the difference between the command value (position command) and the feedback value (rotation angle of the second motor 37) is zero.

[0082]

The torque command ΔP3 is described below.

The road surface reaction is small when the vehicle is moving. Therefore, when the vehicle is moving, a torque command ΔP3 is set such that the turning range obtained by the thrust (output torque) obtained when the motor shaft 39 is driven only by the second motor 37 is identical to the turning range obtained during normal operation of both systems included in the steering control apparatus.

[0083]

When turning while the vehicle is stopped, the road surface reaction is great. Therefore, with the thrust generated by the second motor 37 alone based on the torque

command ΔP3, the turning range is obtained that is narrower than that obtained during the normal operation of both systems included in the steering control apparatus.

[0084]

In the present embodiment, the torque command ΔP3 is the same value as the torque command ΔP2 in the normal control mode.

The structure of the current controller 22C in the failure control mode is identical to that of the current controller 21C in the normal control mode. The same reference numerals are given to those components that are like or the same as the corresponding components of the current controller 21C shown in Fig. 6 and explanations are omitted.

[0085]

The current loop gain of the PI controllers 64 and 65 of the current controller 22C in this embodiment is desirably set so as to be different from that of the normal control mode. The current loop gain is the integral gain and proportional gain in the PI controllers 64 and 65. The gains in the failure control mode are greater than the gains in the normal control mode.

[0086]

Since the current loop gain is set so as to be greater in the failure control mode than in the normal control mode, there is no reduction in responsiveness relative to the operation of the steering wheel 10 or reduction in follow-up relative to the operation of the steering wheel 10.

[0087]

The various parts of the current controller 22C process the torque command ΔP3, detection signal of the second rotation angle sensor 53, and current detection signals relating to the excitation currents iu and iv supplied from the current sensors 71 and 72, which will be described below. The pulse signals (PWM control signals) generated by this processing are supplied from the second ECU 22 to the second

drive circuit 57. The second drive circuit 57 applies a drive voltage generated in accordance with the pulse signals (PWM control signals) to each phase of the second motor 37.

[0088]

As described above, the current controller 22C controls current in the failure control mode such that the difference between the command value (torque command ΔP3) and the feedback value (current value iq and current value id of the second motor 37) is zero.

[0089]

This current control is equivalent to torque control.

(First Drive Circuit 55, Second Drive Circuit 57)

As described above, the steering control apparatus of the present embodiment has a redundant structure formed by the two systems.

[0090]

One of the systems, that is, the first system SY1 includes the first ECU 21, the first steering angle sensor 14, the first drive circuit 55, and the first motor 36.

The remaining system, that is, the other one of the systems (the second system SY2) includes the second ECU 22, the second steering angle sensor 15, the second drive circuit 57, and the second motor 37.

[0091]

The structure of the first drive circuit 55 and the peripheral circuitry thereof is described below with reference to Fig. 4. Fig. 4 is an electric circuit diagram of the first drive circuit 55 and the peripheral circuitry thereof.

Since the structures of the second drive circuit 57 and the peripheral circuitry thereof are identical to that of the first drive circuit 55 and the peripheral circuitry thereof, detailed explanations of the second drive circuit 57 and the peripheral circuitry thereof are omitted. Instead, the reference numerals of the second drive circuit 57 and the peripheral circuitry thereof are indicated in parentheses in

Fig. 4 corresponding to the described structure of the first drive circuit 55 and the peripheral circuitry thereof.

[0092]

The first drive circuit 55 includes a series-connected circuit configured by field-effect transistors (FETs) 81U and 82U, a series-connected circuit configured by FETs 81V and 82V, and a series-connected circuit configured by FETs 81W and 82W. Each series-connected circuit is supplied with voltage from a battery B installed in the vehicle or a generator. Figs. 1 and 4 show that each series-connected circuit is connected to the battery B. A node 83U disposed between the FETs 81U and 82U is connected to the U-phase coil of the first motor coil 41, a node 83V disposed between the FETs 81V and 82V is connected to the V-phase coil of the first motor coil 41, and a node 83W disposed between the FETs 81W and 82W is connected to the W-phase coil of the first motor coil 41.

[0093]

Two current sensors 71 and 72 are provided in two of the three-phase excitation current paths. The current sensors 71 and 72 respectively detect two excitation currents iu and iv among the three-phase excitation currents iu, iv, and iw of the first motor 36, and supply the currents to the first ECU 21.

[0094]

The first ECU 21 supplies PWM control signals to the FETs 81U, 82U, 81V, 82V, 81W, 82W.

The first drive circuit 55 generates three-phase excitation currents in accordance with the PWM control signals, and respectively supplies these three-phase excitation currents to the first motor 36 through the three-phase excitation current paths.

[0095]

As shown in Figs. 1 and 4, a power supply relay 90 is provided between the battery B (or generator) and a series-connected circuit application point Q1. The power supply

relay 90 is normally closed, but is opened in response to a control signal from the second ECU 22.

[0096]

A phase release relay 210 is provided between the node 83U between the FETs 81U and 82U of the first drive circuit 55 and the node of the U-phase coil of the first motor 36.

Furthermore, a phase release relay 220 is provided between the node 83W between the FETs 81W and 82W of the first drive circuit 55 and the node of the W-phase coil of the first motor 36. Although the phase release relays 210 and 220 are normally closed, they are opened in response to a control signal from the second ECU 22.

[0097]

Furthermore, the first ECU 21 and the second ECU 22 are provided with mutual monitoring functions (watchdog function) for normal mutual communication and exchanging calculated actual rotation angle of the first motor 36 and the second motor 37, detection values of sensors of the associated system, other information required for motor control and error information (abnormality determination signal). For example, when the rotation angle of the motor shaft 39 calculated by both ECUs match, the ECUs determine that the other ECU is normal since the motor shaft 39 is shared. If there is abnormality, the ECU communicates error information (abnormality determination signal) to the other ECU. In the following description, error information sent from the first ECU 21 to the second ECU 22 is designated $\alpha 12$, and error information sent from the second ECU 22 to the first ECU 21 is designated $\alpha 21$.

[0098]

When one system determines the other system is abnormal, the one system turns OFF the power supply relay 90, and phase release relays 210 and 220 of the other system.

[0099]

The first ECU 21 and the second ECU 22 respectively

correspond to control means and impairment detecting means of the first system SY1 and second system SY2.

(Operation of First Embodiment)

The operation of the steering control apparatus configured as described above is described below.

[0100]

Fig. 8 is a flow chart of the control program for the steering control executed by the first ECU 21 at predetermined intervals.

In step S10, it is determined whether or not it is starting time of the engine, which is not shown, or whether the engine has been started. This determination is made based on whether it is within a predetermined time after an ON signal from an ignition switch (not shown) has been supplied to the first ECU 21 of the first system SY1, that is whether it is within a predetermined time after a rising edge of the ON signal has occurred. When starting the engine, the first ECU 21 executes processing of the start control mode in step S20 and temporarily ends the procedure.

[0101]

Accordingly, the first ECU 21 of the first system SY1 is set in the start control mode within the period after the receipt of the ON signal from the ignition switch until the predetermined time has elapsed. The second ECU 22 of the second system SY2 enters the start control mode in response to a torque command $\Delta P2$ from the first ECU 21.

[0102]

When the predetermined time has elapsed after receiving the ON signal from the ignition switch, the decision outcome of step S10 is negative, and it is determined in step S30 whether or not the first system SY1 is abnormal.

[0103]

The determination is made based on error information $\alpha 21$ (abnormality determining signal) from the second ECU 22.

The second ECU 22 and the first ECU 21 are linked by a

communication line (not shown). The second ECU 22 determines whether or not the first system SY1 is abnormal based on the computed actual rotation angle of the first motor 36, which is received from the first ECU 21, detection values of sensors of the its own system, and various types of information required for motor control.

[0104]

Abnormalities of the first system SY1 include abnormalities of one or more structural elements of the first system SY1, such as sensors (first steering angle sensor 14), the first ECU 21, the first drive circuit 55 and the like.

[0105]

When it is determined that the first system SY1 is normal in step S30 based on the error information α21 (abnormality determining signal) from the second ECU 22, then in step S40, the process of the normal control mode is executed, and the procedure is temporarily ended. In step S40, the first motor 36 and the second motor 37 of the respective systems are driven simultaneously in accordance with the distributed torque command ΔP1 and the torque command ΔP2.

[0106]

In the second system SY2, the normal control mode is executed in response to the torque command ΔP2 supplied from the first ECU 21 set in the normal control mode.

[0107]

When it is determined that the first system SY1 is abnormal in step S30 based on the error information α21 from the second ECU 22, then in step S50, the failure process is executed and the flowchart is ended. In the failure process, supply of PWM control signals to the first drive circuit 55 is stopped. The second ECU 22 turns OFF the power supply relay 90 and the phase release relays 210 and 220 of the first system SY1 simultaneously with the output of the error information α21.

[0108]

As a result, an excitation current is not supplied to the first motor coil 41 of the first motor 36. At this time, the thrust (output torque) of the first motor 36 stops.

In the second system SY2, the second ECU 22 enters the failure control mode after outputting the error information α21.

[0109]

This time, since the second motor 37 of the second system SY2 is continuously driven, the thrust (output torque) of the motor shaft 39 is reduced to half. Even if the other system becomes abnormal as described above, the second ECU 22 of the remaining system controls such that the output torque (output) is equal to the output torque (output) during the normal operation time.

[0110]

However, when the vehicle is moving, it is possible to adequately turn the front tires T (steered wheels) even though the thrust (output torque) of the motor shaft 39 is half the thrust (output torque) during the normal operation time.

[0111]

Furthermore, since the phase release relays 210 and 220 of the first system SY1 are turned OFF, the first motor 36 does not generate power, and there is no power generation damping to diminish the thrust of the second motor 37.

[0112]

The preferred embodiment has the following advantages.

(1) The steering control apparatus of the preferred embodiment is provided with the systems, which include the first motor 36 and the second motor 37 arranged coaxially on the front tires T (steered wheels) of the steering mechanism 200 and having essentially identical performance, and the ECUs 21 and 22 (control means) for respectively controlling the motors 36 and 37. The systems simultaneously control the associated motors to drive the common steering mechanism 200.

[0113]

The first ECU 21 of the first system SY1 generates a torque command ΔP (first torque command) required for driving the steering mechanism 200 based on the steering position of the steering wheel 10 and the position information of the associated motor of the system, and distributes the torque command ΔP in accordance with the total number of systems. Then, the first ECU 21 controls the torque of the motor in accordance with the torque command ΔP1 distributed to the associated system. Furthermore, the second ECU 22 (control means) of the other system controls the torque of the associated motor of the system in accordance with the torque command ΔP2 distributed to the system.

[0114]

In this way, one system manages a high order control loop (position control), calculates the torque required for the entire steering control apparatus, and distributes it as the torque command to the other system. Each system performs a torque control (low order control loop).

[0115]

Since the position control is performed by the first system SY1 alone even when both motors of the two systems are driven together, there is no torque interference between the motors, and there is no reduction in torque caused by torque interference. Since the torque is not reduced, there is no reduction in responsiveness or follow-up relative to the operation of the steering wheel 10.

[0116]

Since there is no torque interference, noise, vibration, and heat are not generated.

Fig. 9 is a reference example of the conventional structure.

[0117]

In this case, the first system SY1 includes the position controller 21A and the current controller 21C and the second system SY2 includes the position controller 22A and the

current controller 22C. In Fig. 9, for the convenience of explanation, the same reference numerals are given to those components corresponding to the components of the preferred embodiment and the explanations are omitted.

[0118]

With this structure, the systems respectively execute position feedback control based on the rotation angles of the first motor 36 and the second motor 37 detected by the first rotation angle sensor 52 and the second rotation angle sensor 53 provided on the first motor 36 and the second motor 37. However, the motors are controlled to mutually different positions due to assembly errors of both the motors and assembly errors of both the rotation angle sensors 52 and 53, such that torque is reduced because the generated torque directions do not match, noise and vibration are generated, and the electric motor generates heat.

[0119]

The first embodiment solves such problems.

(2) In the first embodiment, the first ECU 21 and the second ECU 22 are impairment detecting means, which detect impairment of the system other than its own system. When the first system SY1, which generates the torque command $\Delta P10$, is impaired, the second ECU 22 (control means) of the second system SY2 generates a torque command $\Delta P3$ (second torque command) based on position information of the motor of the associated system and the steering position of the steering wheel 10.

[0120]

The second ECU 22 then distributes the torque command $\Delta P3$ (second torque command) in accordance with the number of normally operating systems (one in the first embodiment), and controls the torque of the motor in accordance with the torque command $\Delta P3$ distributed to the associated system.

[0121]

Accordingly, even when the first system SY1 is impaired,

backup is performed by driving the second motor 37 with the second system SY2.

In this way, in a case where one system is impaired, when the system which manages the high order control loop (position control) is included in the system which is impaired, one of the other normal systems freshly manages the high order control loop so as to again distribute the calculated total required torque in accordance with the number of normally operating systems.

[0122]

Since the motors having essentially identical performance are arranged integrally and coaxially, there is no restriction due to the difference in performance between the motors. Therefore, the distribution of torque when an impairment occurs is made easier, and there is no reduction in performance.

[0123]

(3) According to the first embodiment, when the first system SY1 is impaired, the current controller 22C of the second system SY2 increases the current loop gain to be greater than that in the normal control mode so as to supplement the first system SY1 and suppress a reduction in responsiveness to the operation of the steering wheel 10 when the first system SY1 is impaired.

[0124]

Accordingly, a reduction in responsiveness to the operation of the steering wheel 10 is suppressed when the first system SY1 is impaired.

(Second Embodiment)

A second embodiment will now be described with reference to Figs. 10 and 11.

[0125]

The hardware structure of the steering control apparatus according to the second embodiment is identical to that of the first embodiment. Therefore, the same reference numerals are

given to those components that are like or the same as the corresponding components of the first embodiment and detailed explanations are omitted. The differences will mainly be discussed.

[0126]

In the first embodiment, position feedback control and current feedback control are performed. The second embodiment differs from the first embodiment in that speed feedback control is performed in addition to position feedback control and current feedback control.

[0127]

(Start Control Mode and Normal Control Mode of First ECU 21)

Fig. 10 illustrates, inside the dashed line, the structure of the control block of the first ECU 21 and the second ECU 22 in the normal control mode of the first system SY1.

[0128]

In the start control mode and the normal control mode, the first ECU 21 executes the steering control of the first motor 36 via the first drive circuit 55 so as to obtain the turning angle (turning angle of the steered wheels) corresponding to the steering angle detected by the first steering angle sensor 14, and so as to generate the thrust required for the motor shaft 39 for that purpose.

[0129]

Specifically, the position controller 21A receives the steering angle detected by the first steering angle sensor 14 as a position command. Furthermore, the position controller 21A receives a detection signal from the first rotation angle sensor 52, and calculates the rotation angle of the motor shaft 39 relative to the stator 38 based on this detection signal. The detection signal of the first rotation angle sensor 52 includes position information of the electric motor.

[0130]

The position controller 21A calculates the difference between the calculated rotation angle of the electric motor (first motor 36) and the steering position based on the steering angle, which is the position command. The position controller 21A multiplies this difference by a predetermined gain required for the position control, and supplies this multiplication value to a speed controller 21D as a speed command C1.

[0131]

A differential processor 21E calculates the motor speed based on the detection signal of the first rotation angle sensor 52, and provides the calculated value to the speed controller 21D.

The speed controller 21D calculates the difference between the speed command C1 and the motor speed, multiplies this difference by a predetermined gain required for speed control so as to generate a torque command ΔP10, and provides this torque command ΔP10 to the torque distributor 21B.

[0132]

The torque command ΔP10 is equivalent to the first torque command generated based on the speed control process result.

The torque distributor 21B divides the supplied torque command ΔP10 by a predetermined division ratio and respectively supplies the divided torque commands ΔP11 and ΔP12 to the current controller 21C of the first system SY1 and the current controller 22C of the second system SY2.

[0133]

In the second embodiment, when both systems included in the steering control apparatus are normal, it is desirable that the torque distributor 21B changes the distribution ratio such that the distribution ratio when starting the engine of the vehicle is different from the distribution ratio at times other than when starting the engine in the same manner as in the first embodiment.

[0134]

That is, when starting the engine of the vehicle (in the start control mode), the distribution ratio is 50:0 (= ΔP11:ΔP12), and at times other than when starting the engine (in the normal control mode), the distribution ratio is 50:50 (=ΔP11:ΔP12).

[0135]

The steering control of the first motor 36 executed by the first ECU 21 includes position control for controlling the turning angle to an angle corresponding to the steering angle, speed control for controlling the motor speed to a speed corresponding to the speed command C1, and torque control for obtaining a thrust required for the motor shaft 39, i.e., for obtaining the output torque.

[0136]

Since the structure of the current controller 21C is identical to that of the first embodiment, the current controller 21C will not be described.

The current controller 21C controls the current feedback such that the difference between the command value (torque command ΔP11) and the feedback value (current value iq and current value id of the first motor 36) is zero.

[0137]

The current control corresponds to the torque control.

(At failure of the first system SY1)

When the first system SY1 is impaired, the first ECU 21 of the first system SY1 stops the control of the first motor 36, as shown in Fig. 11.

[0138]

1. Second ECU 22

The second ECU 22 is a microcomputer having calculation functions, processing functions, and memory functions, and having a start control mode, normal control mode, and failure control mode.

[0139]

The second ECU 22 includes a current controller 22C in a

start control mode and a normal control mode as shown in Fig. 10, and a position controller 22A, current controller 22C, a speed controller 22D, and a differential processor 22E in an failure control mode as shown in Fig. 11.

[0140]

(Start Control Mode and Normal Control Mode of Second ECU 22)

In the start control mode and normal control mode, the current controller 22C receives a torque command ΔP12, a detection signal of the second rotation angle sensor 53, and current detection signals relating to the two excitation currents iu and iv among the three-phase excitation currents iu, iv, and iw of the second motor 37 supplied from the current sensors 71 and 72, as shown in Fig. 10.

[0141]

Like the current controller 21C, the current controller 22C includes a torque current converter, a pair of PI controllers, a d/q inverter, a pulse width modulator, a d/q converter, and an angle detector.

[0142]

The structure of the current controller 22C in the normal control mode is identical to that of the current controller 21C. The same reference numerals are given to those components that are like or the same as the corresponding components of the current controller 21C and detailed explanations are omitted.

[0143]

In the same manner as the various parts of the current controller 21C, the various parts of the current controller 22C process the torque command ΔP12, a detection signal of the second rotation angle sensor 53, and current detection signals relating to the excitation currents iu and iv supplied from the current sensors 71 and 72, which will be described below. The pulse signals (PWM control signals) generated by this processing are supplied from the second ECU 22 to the second

drive circuit 57. The second drive circuit 57 applies a drive voltage generated in accordance with the pulse signals (PWM control signals) to each phase of the second motor 37.

[0144]

As described above, the current controller 22C controls current feedback such that the difference between the command value (torque command ΔP12) and the feedback value (current value iq and current value id of the second motor 37) is zero.

[0145]

The current control corresponds to the torque control.

In the start control mode, since the torque distributor 21B sets the distribution ratio to 50:0 (=ΔP11:ΔP12), the torque command ΔP12 supplied to the current controller 22C is zero. Accordingly, the second motor 37 is not actually driven by the second ECU 22.

[0146]

(Failure Control Mode of Second ECU 22)

The steering control of the second motor 37 executed by the second ECU 22 in the failure control mode includes position control for controlling the turning angle to an angle corresponding to the steering angle, speed control for controlling the motor speed to a speed corresponding to the speed command C2, and torque control for obtaining a thrust required for the motor shaft 39, i.e., for obtaining the output torque.

[0147]

In the failure control mode, the second ECU 22 executes the steering control of the second motor 37 via the second drive circuit 57 so as to have the turning angle (the turning angle of the steered wheels) correspond to the steering angle detected by the second steering angle sensor 15, or to obtain the thrust required for the motor shaft 39 for that purpose.

[0148]

Specifically, the position controller 22A receives the steering angle detected by the second steering angle sensor 15

as a position command. Furthermore, the position controller 22A receives a detection signal from the second rotation angle sensor 53, and calculates the rotation angle of the motor shaft 39 relative to the stator 38 based on this detection signal.

[0149]

The detection signal from the second rotation angle sensor 53 corresponds to position information of the second motor 37 (electric motor).

The position controller 22A calculates the difference between the calculated rotation angle of the electric motor (second motor 37) and the steering position based on the steering angle, which is the position command. The position controller 22A multiplies this difference by a predetermined gain required for the position control, and supplies this multiplication value to the speed controller 22D as the speed command C2.

[0150]

The differential processor 22E calculates the motor speed based on the detection signal of the second rotation angle sensor 53, and provides the calculated value to the speed controller 22D.

The speed controller 22D calculates the difference between the speed command C2 and the motor speed, multiplies this difference by a predetermined gain required for speed control so as to generate a torque command ΔP13, and provides this torque command ΔP13 to the current controller 22C.

[0151]

The torque command ΔP13 is equivalent to the second torque command generated based on the speed control process result.

The speed controller 22D performs speed control such that the difference between the command value (speed command C2) and the feedback value (motor speed of the second motor 37) is zero.

[0152]

The torque command ΔP13 is described below.

The road surface reaction is small when the vehicle is moving. Therefore, when the vehicle is moving, a torque command ΔP13 is set such that the turning range obtained by the thrust (output torque) obtained when the motor shaft 39 is driven only by the second motor 37 is identical to the turning range obtained during normal operation of both systems included in the steering control apparatus.

[0153]

When turning while the vehicle is stopped, the road surface reaction is great. Therefore, the torque command ΔP13 is set such that the turning range is obtained that is narrower than that during the normal operation of both systems included in the steering control apparatus with the thrust generated by the second motor 37 alone.

[0154]

In this embodiment, the torque command ΔP13 is a value identical to the torque command ΔP12 of the normal mode.

The structure of the current controller 22C in the failure control mode is identical to that of the current controller 21C in the normal control mode. The same reference numerals are given to those components that are like or the same as the corresponding components of the current controller 21C shown in Fig. 6 and explanations are omitted.

[0155]

The current loop gain of the PI controllers 64 and 65 of the current controller 22C in this embodiment is desirably set so as to be different from that of the normal control mode. The current loop gain is the integral gain and proportional gain in the PI controllers 64 and 65. The gains in the failure control mode are greater than the gains in the normal control mode.

[0156]

Since the current loop gain is set so as to be greater in

the failure control mode than in the normal control mode, there is no reduction in responsiveness relative to the operation of the steering wheel 10 or reduction in follow-up relative to the operation of the steering wheel 10.

[0157]

The various parts of the current controller 22C process the torque command ΔP13, detection signal of the second rotation angle sensor 53, and current detection signals relating to the excitation currents iu and iv supplied from the current sensors 71 and 72. The pulse signals (PWM control signals) generated by this processing are supplied from the second ECU 22 to the second drive circuit 57. The second drive circuit 57 applies a drive voltage generated in accordance with the pulse signals (PWM control signals) to each phase of the second motor 37.

[0158]

As described above, the current controller 22C controls current in the failure control mode such that the difference between the command value (torque command ΔP13) and the feedback value (current value iq and current value id of the second motor 37) is zero.

[0159]

The current control corresponds to the torque control.

In the second embodiment also, the first ECU 21 and the second ECU 22 respectively correspond to control means and impairment detecting means of the first system SY1 and second system SY2.

[0160]

(Operation of Second Embodiment)

In the second embodiment also, the first ECU 21 executes the flowchart of the control program for the steering control shown in Fig. 8 at predetermined intervals in the same manner as the first embodiment. At this time, the second ECU 22 operates in the same manner as in the first embodiment.

[0161]

The second embodiment has the following advantages.

(1) In the steering control apparatus of the second embodiment, the first ECU 21 (control means) of the first system SY1, in the normal control mode, executes position control based on the steering position of the steering wheel 10 and the position information of the first motor 36. The first ECU 21 executes speed control based on the command value (speed command C2) and feedback value (motor speed of the second motor 37).

[0162]

The first ECU 21 (control means) generates a torque command ΔP10 (first torque command) based on the speed control process result, and distributes the torque command ΔP10 in accordance with the number of systems. The first ECU 21 executes torque control relative to the first motor 36 based on the torque command ΔP11 distributed to the associated system and the actual currents (excitation currents iu, iv, and iw) of the first motor 36 of the associated system.

[0163]

In the normal control mode, the second ECU 22 (control means) of the second system SY2 executes torque control relative to the second motor 37 of the second system SY2 based on the torque command ΔP12 distributed to the second system SY2 and the actual currents (excitation currents iu, iv, and iw) of the second motor 37.

[0164]

In this way, one system manages a high order control loop (position control and speed control), calculates the torque required for the entire steering control apparatus, and distributes it as the torque command to the other system. Each system performs a torque control (low order control loop).

[0165]

As a result, like the first embodiment, since the position control is performed by the first system SY1 alone even when both motors of the two systems are driven together,

there is no torque interference between the motors, and there is no reduction in torque caused by torque interference. Since the torque is not reduced, there is no reduction in responsiveness or follow-up relative to the operation of the steering wheel 10.

[0166]

Since there is no torque interference, noise, vibration, and heat are not generated.

Fig. 18 is a reference example of the conventional structure.

[0167]

In this case, the first system SY1 includes the position controller 21A, the speed controller 21D, and the current controller 21C and the second system SY2 includes the position controller 22A, the speed controller 22D, and the current controller 22C. In Fig. 18, for the convenience of explanation, the same reference numerals are given to those components corresponding to the components of the preferred embodiment and the explanations are omitted.

[0168]

With this structure, the systems respectively execute position feedback control based on the rotation angles of the first motor 36 and the second motor 37 detected by the first rotation angle sensor 52 and the second rotation angle sensor 53 provided in the first motor 36 and the second motor 37. However, the motors are controlled to mutually different positions due to assembly errors of both the motors and assembly errors of both the rotation angle sensors 52 and 53, such that torque is reduced because the generated torque directions do not match, noise and vibration are generated, and the electric motor generates heat.

[0169]

The second embodiment solves such problems.

(2) In the second embodiment, when the first system SY1 is impaired, the second ECU 22 (control means) of the second

system SY2 executes position control based on the steering position of the steering wheel 10 and the position information of the second motor 37 of the second system SY2. Furthermore, the second ECU 22 generates a command value (speed command C1) based on the position control process result, and executes speed control based on the resulting command value (speed command C1) and the feedback value (motor speed of the second motor 37).

[0170]

Furthermore, the second ECU 22 generates a torque command ΔP13 (second torque command) based on the speed control process result, and executes torque control on the second motor 37 based on this torque command ΔP13 (second torque command) and the actual currents (excitation currents iu, iv, and iw) of the second motor 37 of the second system SY2.

[0171]

Accordingly, even when the first system SY1 is impaired, backup is performed by driving the second motor 37 with the second system SY2.

In this way, in a case where one of the systems is impaired, when the system which manages the high order control loop (position control and speed control) is included in the systems which are impaired, one of the other normally operating systems freshly manages the high order control loop so as to again distribute the calculated total required torque in accordance with the number of normal systems.

[0172]

Since the motors having essentially identical performance are arranged integrally and coaxially, there is no restriction due to the difference in performance between the motors. Therefore, the distribution of torque when an impairment occurs is made easier, and there is no reduction in performance.

[0173]

(3) According to the second embodiment, when the first

system SY1 is impaired, the current controller 22C of the second system SY2 increases (varies) the current loop gain to be greater than that in the normal control mode so as to supplement the first system SY1 and suppress a reduction in responsiveness to the operation of the steering wheel 10 when the first system SY1 is impaired.

[0174]

Accordingly, a reduction in responsiveness to the operation of the steering wheel 10 is suppressed when the first system SY1 is impaired.

(Third Embodiment)

A third embodiment will now be described with reference to Figs. 12 and 17.

[0175]

Among the hardware structure of the steering control apparatus according to the third embodiment, the same reference numerals are given to those components that are like or the same as the corresponding components of the second embodiment and detailed explanations are omitted. The differences will mainly be discussed.

[0176]

Fig. 12 is a schematic view showing a steering control apparatus according to the third embodiment.

The steering control apparatus is provided with an operating mechanism 100 including a steering wheel 10, a steering mechanism 200, which is a vehicle steering mechanism in this embodiment, and a control section 300.

[0177]

(Manipulation Mechanism 100)

The third embodiment differs from the second embodiment in that the rotary shaft 11 is provided with a third steering angle sensor 16 for detecting the steering angle of the steering wheel 10 corresponding to the rotation angle of the rotary shaft 11 in addition to the first steering angle sensor 14 and the second steering angle sensor 15.

[0178]

The third steering angle sensor 16 is electrically connected to a third ECU 23.

(Steering Mechanism 200)

The third embodiment differs from the second embodiment in that the steering mechanism 200 includes, in addition to the first motor 36 and the second motor 37, a third motor 43 arranged coaxially with the motors.

[0179]

That is, in the third embodiment, the first motor 36, second motor 37, and third motor 43 have a common stator and rotor, or motor shaft 39, and are arranged coaxially. As a result, the third motor 43 is arranged integrally and coaxially with the first motor 36 and the second motor 37. All motors are three-phase synchronous type brushless DC motors having essentially identical performance. The third motor 43 is controlled by a third drive circuit 58.

[0180]

The first drive circuit 55 functions as a first drive means, the second drive circuit 57 functions as a second drive means, and the third drive circuit functions as a third drive means.

In the third embodiment, in addition to the first rotation angle sensor 52 and the second rotation angle sensor 53, a third rotation angle sensor 54 is arranged along the axial direction of the motor shaft 39. The rotation angle sensors 52, 53, 54 are rotary encoders.

[0181]

The first rotation angle sensor 52, second rotation angle sensor 53, and third rotation angle sensor 54 respectively supply detection signals to the first ECU 21, second ECU 22, and third ECU 23 at predetermined sampling intervals.

[0182]

The first ECU 21, second ECU 22, and third ECU 23 respectively calculate the rotation angle of the motor shaft

39 of the first motor 36, second motor 37, and third motor 43 relative to the stator in accordance with the received detection signal.

[0183]

(Control Section 300)

The control section 300 is described below.

The control section 300 according to the third embodiment includes a first ECU 21, a second ECU 22, a third ECU 23, a first drive circuit 55, a second drive circuit 57, and a third drive circuit 58.

[0184]

The first ECU 21, the second ECU 22, and the third ECU 23 are electronic control units including microcomputers.

Since the hardware structure of the third ECU 23 is identical to the first ECU 21 and the second ECU 22 of the second embodiment, explanation is omitted.

[0185]

The first ECU 21, second ECU 22, and third ECU 23 are connected to one another by a communication line.

Furthermore, the ECUs are provided with mutual monitoring functions (watchdog function) for normal mutual communication and exchanging calculated actual rotation angle of the first motor 36, the second motor 37, and the third motor 43, detection values of associated sensors of their system, various types of information for motor control and error information (abnormality determination signal). That is, the ECU of one system simultaneously monitors the other two systems. Error information sent from one ECU to the other ECUs includes error information of the other two systems monitored by the one ECU. Accordingly, since the ECU of one system receives error information from the ECUs of the other two systems, the ECU of one system determines the condition (normal or abnormal) of all systems or each system based on error information supplied from the other two systems.

[0186]

For example, when the rotation angle of the motor shaft 39 calculated by the ECUs mutually match, the ECUs determine that the other ECUs are normal since the motor shaft 39 is shared. If there is abnormality, the ECUs send error information (abnormality determination signal) to the other ECUs.

[0187]

In the following description, error information sent from the first ECU 21 to the second ECU 22 is designated $\alpha12$, and error information sent from the second ECU 22 to the first ECU 21 is designated $\alpha21$. Furthermore, error information sent from the second ECU 22 to the third ECU 23 is designated $\alpha23$, and error information sent from the third ECU 23 to the second ECU 22 is designated $\alpha32$. Furthermore, error information sent from the first ECU 21 to the third ECU 23 is designated $\alpha13$, and error information sent from the third ECU 23 to the first ECU 21 is designated $\alpha31$.

[0188]

In the third embodiment, the first system SY1 is configured by the first ECU 21, the first steering angle sensor 14, the first drive circuit 55, and the first motor 36.

The second system SY2 is configured by the second ECU 22, the second steering angle sensor 15, the second drive circuit 57, and the second motor 37.

[0189]

The third system SY3 is configured by the third ECU 23, the third steering angle sensor 16, the third drive circuit 58, and the third motor 43.

When one system determines that one of the other systems is abnormal, the former system executes processes to turn OFF the power supply relay 90, phase release relay 210, and phase release relay 220 of one of the other systems, and sets a mode, which will be described below, in accordance with the condition (normal or abnormal) of one of the other systems.

[0190]

That is, as described above, since the ECU of one system determines whether all the systems are normal or abnormal, or whether one of the other systems is normal or abnormal, that ECU executes processes in accordance with the condition of each system.

[0191]

In this way the first ECU 21, second ECU 22, and third ECU 23 function as control means and impairment detection means of the associated system.

The functions of the first ECU 21, second ECU 22, and third ECU 23 of associated systems are described below.

[0192]

1. First ECU 21

In the third embodiment, when starting the engine, when all systems are normal, and when at least one system other than the first system is impaired, the first ECU 21 of the first system SY1 functions as the high order controller of the other systems.

[0193]

(1-1) Start control mode and normal control mode of first ECU 21

Fig. 14 shows the configuration of the control blocks of the first ECU 21 to the third ECU 23 when the first system SY1 to the third system SY3 are normal.

[0194]

The configuration of the first ECU 21 in the start control mode and the normal control mode is identical to that of the second embodiment. Same reference numerals are given to the identical components and explanations are omitted.

The torque command $\Delta P10$ is equivalent to the first torque command generated based on the speed control process result.

[0195]

The distribution manner of the torque distributor 21B differs from the second embodiment.

That is, the torque distributor 21B divides the torque

command ΔP10 into a torque command ΔP11, a torque command ΔP12, and a torque command ΔP14, and supplies them to the current controller 21C of the first system SY1, the current controller 22C of the second system SY2, the current controller 23C of the third system SY3 (refer to Fig. 14).

[0196]

In the third embodiment, if all systems included in the steering control apparatus are normal, the torque distributor 21B changes the distribution ratio such that the distribution ratio when starting the engine of the vehicle is different from the distribution ratio at times other than when starting the engine in the same manner as in the first embodiment.

[0197]

That is, when starting the engine of the vehicle (in the start control mode), the distribution ratio is 100/3:0:0 (= ΔP11:ΔP12:ΔP14), and at times other than when starting the engine (in the normal control mode), the distribution ratio is 100/3:100/3:100/3 (ΔP11:ΔP12:ΔP14).

[0198]

The steering control of the first motor 36 executed by the first ECU 21 includes position control for controlling the turning angle in accordance with the steering angle, speed control for controlling the motor speed so as to correspond to the speed command C1, and torque control for obtaining a thrust, i.e., an output torque, required for the motor shaft 39.

[0199]

The current controller 21C controls the current feedback such that the difference between the command value (torque command ΔP11) and the feedback value (current value iq and current value id of the first motor 36) is zero.

[0200]

The current control is equivalent to the torque control.

(1-2) First Failure Control Mode

When the first system SY1 is normal and either one of the

second and third systems SY3 is abnormal, the first ECU 21 enters the first failure control mode.

[0201]

In the first failure control mode, the torque distributor 21B of the first ECU 21 distributes a torque command ΔP10 to the normal systems and excludes the abnormal system.

[0202]

Fig. 15 shows an example in which the third system SY3 is abnormal and the second system SY2 is normal.

When the second system SY2 is abnormal and the third system SY3 is normal, the description relating to the second system SY2 may be replaced by the third system SY3 in an example of Fig. 15. Therefore, explanation for the case where the second system SY2 is abnormal and the third system is normal is omitted.

[0203]

In the example of Fig. 15, the third ECU 23 of the third system SY3 stops control of the third motor 43.

Then, the torque distributor 21B of the first system SY1 redistributes the torque command ΔP10 for torque command of the first system SY1 and the second system SY2.

[0204]

That is, the torque distributor 21B divides the supplied torque command ΔP10 into a torque command ΔP11a and a torque command ΔP12a, and respectively provides them to the current controller 21C of the first system SY1 and the current controller 22C of the second system SY2 (refer to Fig. 15). The distribution ratio at this time is 50:50 (=ΔP11a:ΔP12a).

In the first failure control mode, the PI controller 64 and the PI controller 65 of the current controllers of each normal system are set so as to have a different current loop gain from one in the normal control mode when all systems are normal. The current loop gain is the integral gain and proportional gain in the PI controller 64 and PI controller 65. These gains in the failure control mode are set so as to be

greater than these gains in the normal control mode.

[0205]

Since the current loop gain in the first failure control mode is set so as to be greater than the current loop gain in the normal control mode, there is no decrease in the responsiveness relative to the operation of the steering wheel 10, and there is no reduction in follow-up of the operation of the steering wheel 10.

[0206]

The torque command ΔP10 is described below.

According to the example of Fig. 15, since the road surface reaction is small when the vehicle is moving, when the vehicle is moving, a torque command ΔP10 is set such that the turning range obtained by the thrust (output torque) obtained when the motor shaft 39 is driven by the first and second motors 37 is identical to the turning range obtained during normal operation of all systems included in the steering control apparatus.

[0207]

When turning while the vehicle is stopped, the road surface reaction is great. Therefore, the torque command ΔP10 is set such that the turning range is obtained that is narrower than that during the normal operation of all systems included in the steering control apparatus with the thrust (output torque) obtained by the first motor 36 and the second motor 37.

[0208]

In the present embodiment, the torque command ΔP10 is a value identical to the total value of the torque commands ΔP11 and ΔP12 in the normal control mode (refer to Fig. 14).

2. Second ECU 22 and third ECU 23

The second ECU 22 and the third ECU 23 are described below.

[0209]

(2-1) Start control mode and normal control mode of first

ECU 21

When the first ECU 21 is in the normal control mode, the second ECU 22 and the third ECU 23 include the current controller 22C and the current controller 23C as shown in Fig. 14. The current controller 22C and the current controller 23C receive distributed torque commands ΔP12 and ΔP14.

[0210]

The structure of the current controller 22C and the current controller 23C in the normal control mode is identical to that of the current controller 21C. The same reference numerals are given to those components that are like or the same as the corresponding components of the current controller 21C shown in Fig. 6 and explanations are omitted.

[0211]

The current controller 22C executes current feedback control such that the difference between the command value (torque command ΔP12) and the feedback value (current value iq and current value id of the second motor 37) is zero.

[0212]

The current controller 23C executes current feedback control such that the difference between the command value (torque command ΔP14) and the feedback value (current value iq and current value id of the third motor 43) is zero.

[0213]

The current control corresponds to the torque control.

(2-2) Second Failure Control Mode

Control when the first system SY1 is impaired is described below.

[0214]

When the first system SY1 is impaired and the second system SY2 is normal, the second ECU 22 of the second system SY2 functions as a high order controller than the third ECU 23 of the third system SY3.

[0215]

When the first system SY1 and the second system SY2 are

abnormal and the third system SY3 is normal, the third ECU 23 of the third system SY1 functions as the controller for the steering control apparatus.

[0216]

The second failure control mode is executed when only the first system SY1 is impaired, or when the first system SY1 and either of the other systems is impaired.

[0217]

(2-2-1) When only the first system SY1 is impaired

When only the first system SY1 is impaired, the first ECU 21 of the first system SY1 stops controlling the first motor 36, as shown in Fig. 16.

[0218]

The following is the explanation for the function of the second ECU 22 and the third ECU 23 when the second system SY2 and the third system SY3 are operating normally during this impairment.

[0219]

In the second failure control mode, the second ECU 22 includes the position controller 22A, torque distributor 22B, current controller 22C, speed controller 22D, and differential processor 22E.

[0220]

The steering control of the second motor 37 executed by the second ECU 22 in the second failure control mode includes position control for controlling the turning angle in accordance with the steering angle, speed control for controlling the motor speed so as to correspond to the speed command C2, and torque control for obtaining a thrust, i.e., an output torque, required for the position control.

[0221]

In the second failure control mode, the second ECU 22 executes the steering control of the second motor 37 via the second drive circuit 57 so as to have the turning angle (the turning angle of the steered wheels) correspond to the

steering angle detected by the second steering angle sensor 15, and to obtain the thrust required for the motor shaft 39 for that purpose.

[0222]

Specifically, the position controller 22A receives the steering angle detected by the second steering angle sensor 15 as a position command and the detection signal supplied from the second rotation angle sensor 53, and calculates the rotation angle of the motor shaft 39 relative to the stator based on this detection signal.

[0223]

A detection signal from the second rotation angle sensor 53 corresponds to position information of the second motor 37 (electric motor).

The position controller 22A calculates the difference between the calculated rotation angle of the electric motor (second motor 37) and the steering position based on the steering angle, which is the position command. The position controller 22A multiplies this difference by a predetermined gain required for the position control, and supplies this multiplication value to the speed controller 22D as the speed command C2.

[0224]

The differential processor 22E calculates the motor speed based on the detection signal of the second rotation angle sensor 53, and provides this calculated value to the speed controller 22D.

The speed controller 22D calculates the difference between the speed command C1 and the motor speed, multiplies this difference by a predetermined gain required for speed control, and supplies this multiplication value to the torque distributor 22B as the torque command ΔP13.

[0225]

That is, the speed controller 22D executes speed control such that the difference between the command value (speed

command C2) and the feedback value (motor speed of the second motor 37) is zero.

[0226]

The torque command ΔP13 is equivalent to the second torque command generated based on the speed control process result.

The torque distributor 22B divides the torque command ΔP13 by a ratio corresponding to the number of normal systems, and respectively provides these divided torque commands ΔP15 and ΔP16 to the current controller 22C of the second system SY2 and the current controller 23C of the third system SY3.

[0227]

That is, in this example, the first system SY1 included in the steering control apparatus is abnormal, and the second system SY2 and the third system SY3 included in the steering control apparatus are normal. Therefore, the distribution ratio for the normal systems is 50:50 (=ΔP15:ΔP16).

[0228]

The PI controllers 64 and 65 of the current controllers of each system have different current loop gains in this embodiment than when all systems are normal (normal control mode). The current loop gain is the integral gain and proportional gain in the PI controllers 64 and 65. These gains in the failure control mode are set so as to be greater than these gains in the normal control mode.

[0229]

Since the current loop gain in the second failure control mode is set so as to be greater than the current loop gain in the normal control mode, there is no decrease in the responsiveness relative to the operation of the steering wheel 10, and there is no reduction in follow-up of the operation of the steering wheel 10.

[0230]

The torque command ΔP13 is described below.

The road surface reaction is small when the vehicle is

moving. Therefore, when the vehicle is moving, a torque command ΔP13 is set such that the turning range obtained by the thrust (output torque) obtained when the motor shaft 39 is driven by the second and third motors 43 is identical to the turning range obtained during normal operation of all systems included in the steering control apparatus.

[0231]

When turning while the vehicle is stopped, the road surface reaction is great. Therefore, the torque command ΔP13 is set such that the turning range is obtained that is narrower than that during the normal operation of all systems included in the steering control apparatus with the thrust (output torque) obtained by the second motor 37 and the third motor 43.

[0232]

In the present embodiment, the torque command ΔP13 is a value identical to the total value of the torque commands ΔP12 and ΔP14 in the normal control mode.

The structure of the current controller 22C in the second failure control mode is identical to that of the current controller 21C in the normal control mode. The same reference numerals are given to those components that are like or the same as the corresponding components of the current controller 21C shown in Fig. 6 and explanations are omitted.

[0233]

The parts of the current controller 22C process the torque command ΔP15, detection signal of the second rotation angle sensor 53, and current detection signals relating to the excitation currents iu and iv supplied from the current sensors 71 and 72. The pulse signals (PWM control signals) generated by this processing are supplied from the second ECU 22 to the second drive circuit 57. The second drive circuit 57 applies a drive voltage generated in accordance with the pulse signals (PWM control signals) to each phase of the second motor 37.

[0234]

In this way, in the second failure control mode, the current controller 22C executes current control such that the difference between the command value (torque command ΔP15) and the feedback value (current value iq and current value id of the second motor 37) is zero.

[0235]

The current control corresponds to the torque control.

When only the first system SY1 is impaired, the third ECU 23 includes the current controller 23C as shown in Fig. 16.

[0236]

The current controller 23C executes current feedback control such that the difference between the command value (torque command ΔP16) and the feedback value (current value iq and current value id of the third motor 43) is zero.

[0237]

The current control corresponds to the torque control.

(2-2-2) When the first system SY1 and another system are impaired

When the first system SY1 and one other system are simultaneously impaired, the first ECU 21 of the first system SY1 stops control of the first motor 36, and the ECU of the other impaired system stops control of the motor of that system. This is the second failure control mode.

[0238]

Fig. 17 shows the case where the first system SY1 and the third system SY3 are impaired. In this case, only the second system SY2 is normal.

When the second system SY2 is abnormal and the third system SY3 is normal, the description relating to the second system SY2 may be replaced by the third system SY3 in an example of Fig. 17. Therefore, explanation for the case where the second system SY2 is abnormal and the third system is normal is omitted.

[0239]

In this case, the second ECU 22 includes the position controller 22A, torque distributor 22B, current controller 22C, speed controller 22D, and differential processor 22E as shown in Fig. 17.

[0240]

The structure of each of these parts is identical to the structure shown in Fig. 16, although the distribution ratio of the torque distributor 22B is different. That is, in this example, the distribution ratio of the torque distributor 22B is 100:0 (ΔP15: ΔP16). Accordingly, the torque command ΔP15 provided from the torque distributor 22B to the current controller 22C is identical to the torque command ΔP13. Furthermore, although not shown in the drawing, even though the torque distributor 22B outputs the torque command ΔP16 to the third ECU 23, the torque command ΔP16 is zero.

[0241]

(Operation of Third Embodiment)

In the third embodiment, the first ECU 21 executes a flowchart for the control program of steering control shown in Fig. 13 at predetermined intervals.

[0242]

The operation of the steering control apparatus configured as described above is described below.

In step S100, it is determined whether or not it is engine starting time, which is not shown, or whether the engine has been started as in step S10. When it is the engine starting time, the first ECU 21 executes processing of the start control mode in step S200 and temporarily ends the step.

[0243]

Accordingly, the first ECU 21 of the first system SY1 is set in the start control mode within the period after the receipt of the ON signal from the ignition switch until the predetermined time has elapsed.

The second ECU 22 of the second system SY2 and the third ECU 23 of the third system SY3 enter the start control mode in

response to the torque command ΔP12 and ΔP14 supplied from the first ECU 21.

[0244]

When a predetermined time elapses from when an ON signal from the ignition switch is received, the decision outcome of step S100 is negative. Then, in step S300, it is determined whether or not all systems are normal based on error information supplied from the other systems.

[0245]

When it is determined that all systems are normal in step S300, the process of the normal control mode is executed in step S400 and the process is temporarily ended. In step S400, the first motor 36, second motor 37, and third motor 43 are simultaneously driven in accordance with the torque command ΔP11, torque command ΔP12, and torque command ΔP14 distributed to each system.

[0246]

When it is determined that all systems are not normal in step S300, then, in step S500, it is determined which system has the abnormality based on the error information received from the other systems. When the first system SY1 is abnormal, the process proceeds to step S700, and when the first system SY1 is normal, the process proceeds to step S600.

[0247]

In step S600, a first failure process is executed. That is, the first ECU 21 is in the first failure control mode.

In this mode, the torque distributor 21B of the first ECU 21 redistributes the torque command ΔP10 to the normal systems and excludes the abnormal system. Then, the process is temporarily ended.

[0248]

This time the ECU of the abnormal system stops control of the associated motor.

In step S700, the first ECU 21 executes the second failure process.

[0249]

In this case, the first ECU 21 stops control of the first motor 36, as shown in Fig. 16.

When only the first system SY1 is impaired, the second ECU 22 of the second system SY2 functions as a higher order controller than the third ECU 23 of the third system SY3. That is, the process described in section "2-2-1 When only the first system SY1 is impaired" is executed, and the process is temporarily ended.

[0250]

When the first system SY1 and one other system are impaired, the ECU of the normal system executes the process described in section "2-2-2 When the first system SY1 and another system are impaired", and temporarily ends the process.

[0251]

The third embodiment provides the following advantages.

(1) The steering control apparatus 1 of the third embodiment is provided with a plurality of systems, which include three motors having essentially identical performance and arranged integrally on the same axis, and control means for respectively controlling the motors. The systems simultaneously control the associated motors to drive the common steering mechanism 200.

[0252]

Furthermore, the first ECU 21 of the first system SY1 generates a torque command $\Delta P10$ (first torque command) required for driving the steering mechanism 200 based on the steering position of the steering wheel 10 and the position information of the motor of the associated system, and distributes the torque command $\Delta P10$ in accordance with the number of systems. Then, the first ECU 21 executes torque control for the motor in accordance with the torque command $\Delta P11$ distributed to the associated system. Furthermore, the second ECU 22 and the third ECU 23 (control means) of the other systems execute torque control for the associated motors

of the systems in accordance with the torque commands ΔP12 and ΔP14 distributed to the associated system.

[0253]

In this way, one system manages a high order control loop (position control and speed control), calculates the torque required for the entire steering control apparatus, and distributes it as the torque command to the other systems. Each system performs a torque control (low order control loop).

[0254]

Since the position control is performed by the first system SY1 alone, even when motors of the three systems are driven together, there is no torque interference between the motors, and there is no reduction in torque caused by torque interference. Since the torque is not reduced, there is no reduction in responsiveness or follow-up relative to the operation of the steering wheel 10.

[0255]

Since there is no torque interference, noise, vibration, and heat are not generated.

(2) In the third embodiment, the first ECU 21, second ECU 22, and third ECU 23 are impairment detecting means, which detect impairment of the systems other than its own system. When one or more systems, including the first system SY1 which generates the torque command ΔP10, is impaired, one of the ECUs (control means) of other normal systems generates a torque command ΔP13 (second torque command) based on the steering position of the steering wheel 10 and position information of the motor of its own system.

[0256]

Then, the torque command ΔP13 (second torque command) is distributed in accordance with the number of remaining normal systems, and torque control is executed for the associated motor in accordance with the torque command ΔP15 distributed to its own system.

[0257]

Furthermore, the ECU (control means) of another normal system executes torque control for the associated motor in accordance with the torque command ΔP16 distributed to the associated system.

[0258]

Accordingly, even when the first system SY1 is impaired, another normal system such as the second system SY2 drives the motor of the impaired system and performs back-up.

[0259]

In this way, in a case where one or more of the systems is impaired, when the system which manages the high order control loop (position control and speed control) is included in the systems which are impaired, one of the other normally operating systems freshly manages the high order control loop so as to again distribute the calculated total required torque in accordance with the number of normal systems.

[0260]

Since the motors having essentially identical performance are arranged integrally and coaxially, there is no restriction due to the difference in performance between the motors. Therefore, the distribution of torque when an impairment occurs is made easier, and there is no reduction in performance.

[0261]

(3) In the third embodiment, the first ECU 21, second ECU 22, and third ECU 23 are impairment detecting means for detecting impairment of the systems other than its own system.

[0262]

When one or more systems are impaired excluding the first system SY1 which generated the torque command ΔP10, the first ECU 21 (control means) of the first system SY1 redistributes the torque command ΔP10 (first torque command) to the number of remaining normal systems. Then, the first ECU 21 executes torque control for the electric motor in accordance with the torque command ΔP11a distributed to the associated system.

[0263]

Furthermore, the ECU (control means) of the other normal system (second system SY2 in the example of Fig. 15) executes torque control for the associated motor in accordance with the torque command ΔP12a distributed to the associated system.

[0264]

Accordingly when a system other than the first system SY1 is impaired, the other system such as the first system SY1 drives the motor of the associated system by redistributing the torque command ΔP10 (first torque command) in accordance with the number of remaining normal systems. Therefore back-up is performed.

[0265]

In this way, when the system that managed the high order control loop (position control and speed control) is not included in the impaired systems, the system that managed the high order control loop prior to the impairment manages the high order control loop after impairment, and redistributes the total required torque in accordance with the number of remaining normal systems.

[0266]

Since the motors having essentially identical performance are arranged integrally and coaxially, there is no restriction due to the difference in performance between the motors. Therefore, the redistribution of torque when an impairment occurs is made easier, and there is no reduction in performance.

[0267]

(4) In the torque control of the third embodiment, there is current control for controlling feedback of the current of the motors (electric motors). When all systems are normal and when one or more systems are impaired, the first ECU 21 through the third ECU 23 of the systems change the current loop gain of the current control.

[0268]

Therefore, reduction in responsiveness relative to the operation of the steering wheel 10 is suppressed even when one or more systems are damaged.

The embodiment of the present invention is not limited to the illustrated embodiments, but may be modified as follows.

[0269]

(1) In the above embodiments, the number of systems is two or three, but may be four or more.

In this case, one system manages a high order control loop for position control and current control, and the other systems execute a low order control loop for current control.

[0270]

When one system is abnormal, one of the remaining systems executes position control and current control, and the other systems execute current control.

[0271]

When there are four or more systems and all systems are normal, one system manages a high order control loop for position control, speed control, and current control, and the other systems execute a low order control loop for current control.

[0272]

When one system is abnormal, one of the remaining systems executes position control, speed control, and current control, and the other systems execute current control.

[0273]

That is, when the systems are normal, the steering mechanism 200 is driven by the synthesized output of motors of all systems, and when one system is abnormal, the steering mechanism 200 is driven by the synthesized output torque of motors of the remaining motors.

[0274]

(2) In the first to third embodiments, the rotation angle sensors such as the first rotation angle sensor 52 are rotary encoders. However, as long as the sensor has a motor such as

the first motor 36 and a predetermined electric angle and detects the displacement position of the motor, the rotation angle sensor may be other rotation displacement detecting means such as a resolver or the like.

[0275]

(3) In the above embodiments, the invention is applied to a steer-by-wire type steering control apparatus. However, the invention may be applied to motor-driven power assisted steering control apparatuses. For example, the shaft 35 is changed to a rack shaft, and the rack shaft and steering wheel are coupled by a rack and pinion.

[0276]

[Effects of the Invention]

As described above, according to the invention as set forth in claims 1 to 4, when simultaneously driving the motors of the systems, the problem of torque interference between the electric motors is solved and generation of noise, vibration, and heat is suppressed without decreasing the torque.

[0277]

According to the invention of claims 2 and 3, since the motors having substantially the same performance are arranged integrally and coaxially, the distribution of torque command when impairment occurs is made easier, and there is no reduction in performance of the steering mechanism when impairment occurs.

[0278]

According to the invention as set forth in claim 4, the current loop gains suppressed in view of noise and vibration when all the systems are operating normally is increased to a predetermined value when impairment occurs. Accordingly, the performance of the steering mechanism when impairment occurs is prevented from being reduced.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1] A schematic diagram showing an entire steering control apparatus according to a first embodiment.

[Fig. 2] An enlarged view showing a steering mechanism 200 of the steering control apparatus.

[Fig. 3] A cross sectional view illustrating configuration inside a motor housing 32.

[Fig. 4] An electric circuit diagram of a first drive circuit 55 and its peripheral circuitry.

[Fig. 5] A conceptual diagram of a control block of each system in a normal control mode.

[Fig. 6] A control block diagram of a current controller 21C.

[Fig. 7] A conceptual diagram of a control block of each system in a failure control mode.

[Fig. 8] A flowchart of the control executed by a first ECU 21.

[Fig. 9] A schematic diagram showing a control block of each system according to a reference example in which a prior art method is used.

[Fig. 10] A conceptual diagram of a control block of each system in a normal control mode according to a second embodiment.

[Fig. 11] A conceptual diagram of a control block of each system in a failure control mode according to the second embodiment.

[Fig. 12] A schematic diagram showing an entire steering control apparatus according to a third embodiment.

[Fig. 13] A flowchart executed by a first ECU 21 according to the third embodiment.

[Fig. 14] A conceptual diagram of a control block of each system in a normal control mode according to a third embodiment.

[Fig. 15] A conceptual diagram of a control block of each system in a failure control mode according to the third embodiment.

[Fig. 16] A conceptual diagram of a control block of each system in a second failure control mode according to the third

embodiment.

[Fig. 17] A conceptual diagram of a control block of each system in the second failure control mode according to the third embodiment.

[Fig. 18] A schematic diagram showing a control block of each system according to a reference example in which a prior art method is used.

[Description of the Reference Numerals]

10...steering wheel
21...first ECU (control means)
22...second ECU (control means)
23...third ECU 23 (control means)
36...first motor (electric motor)
37...second motor (electric motor)
43...third motor (electric motor)
52...first rotation angle sensor
53...second rotation angle sensor
54...third rotation angle sensor
55...first drive circuit
57...second drive circuit
58...third drive circuit
200...steering mechanism
T...front wheels (steered wheels)
SY1...first system
SY2...second system
SY3...third system

[Title of Document] Abstract

[Abstract]

[Objective] To provide a vehicle steering control apparatus capable of suppressing generation of noise, vibration, and heat without decreasing torque by solving a problem of torque interference between electric motors of systems when simultaneously operating the electric motors.

[Means for Solving the Problems] A first system and a second system respectively including a first ECU 21 and a second ECU 22 are provided. The first ECU 21 executes position control based on the steering position of the steering wheel and the position information of a first motor 36. The first ECU 21 generates a torque command ΔP based on a computation result of the position control, and distributes the torque command ΔP in accordance with the number of systems. The first ECU 21 executes torque control relative to the first motor 36 based on the torque command ΔP1 distributed to the associated system and the actual currents of the first motor 36 of the associated system. The second ECU 22 executes torque control relative to a second motor 37 based on the distributed torque command ΔP2 and the actual currents of the second motor 37.

[Selected Drawing] Fig. 5

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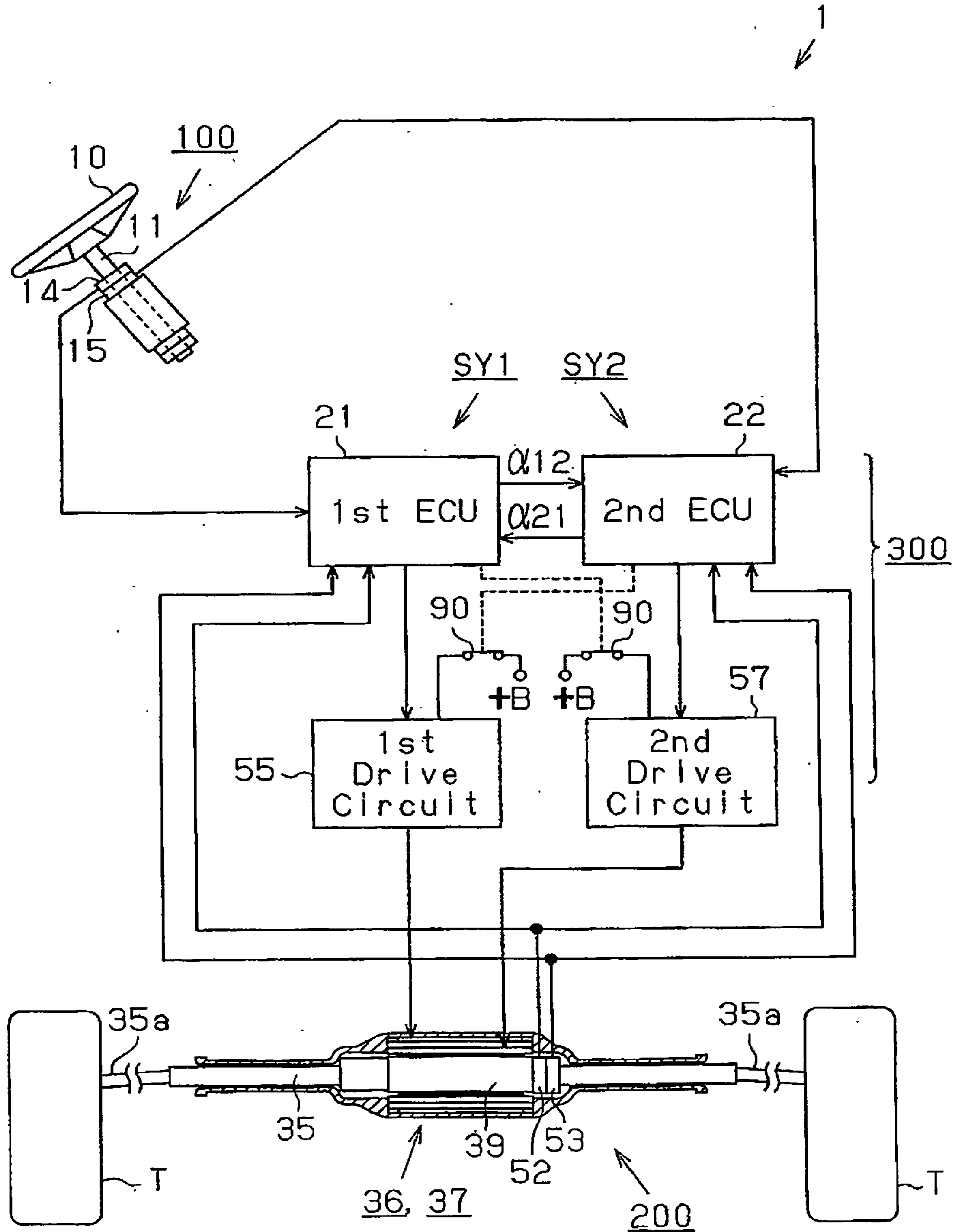
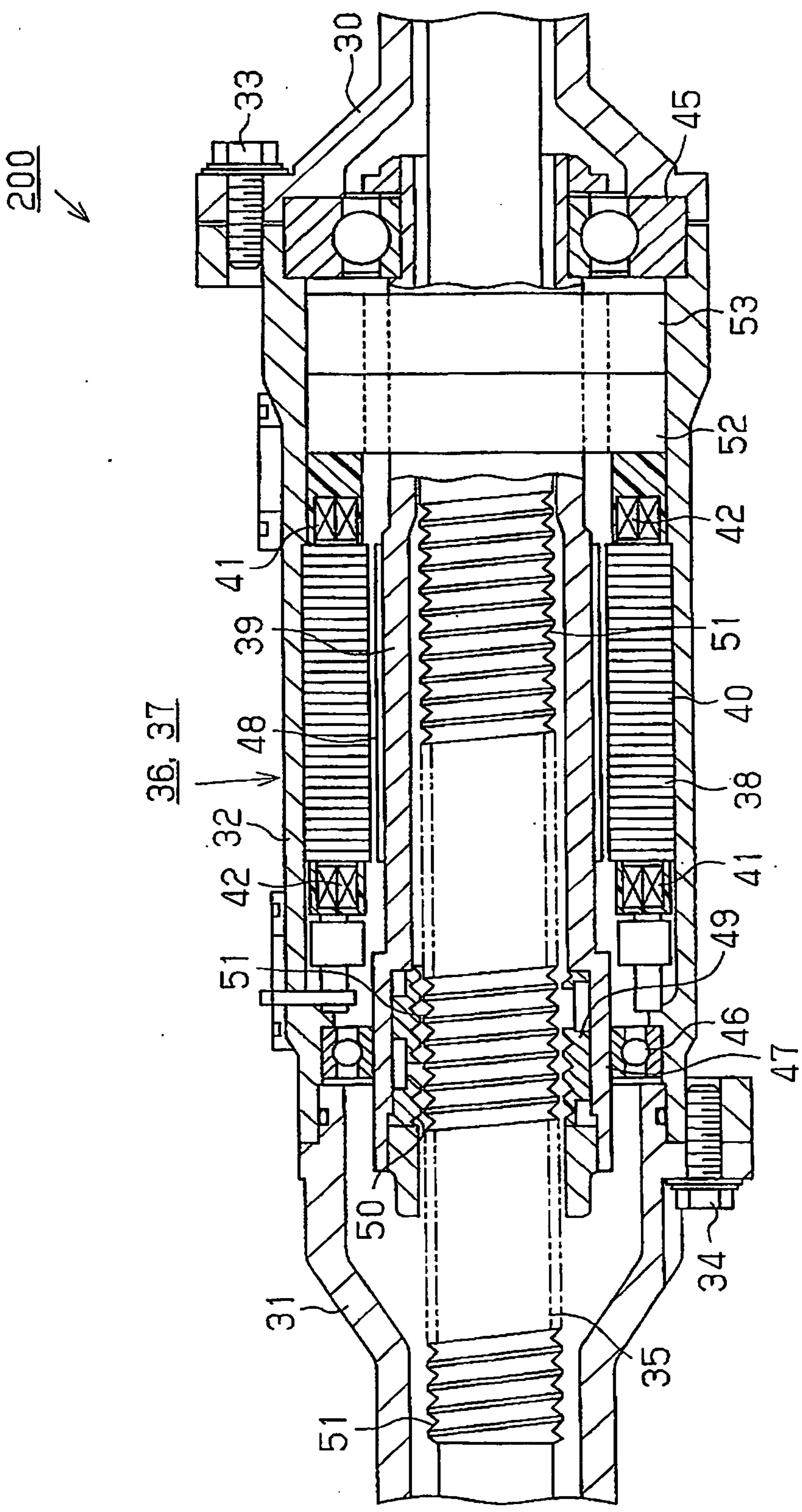
[Title of Document] Drawings

[Fig. 1]

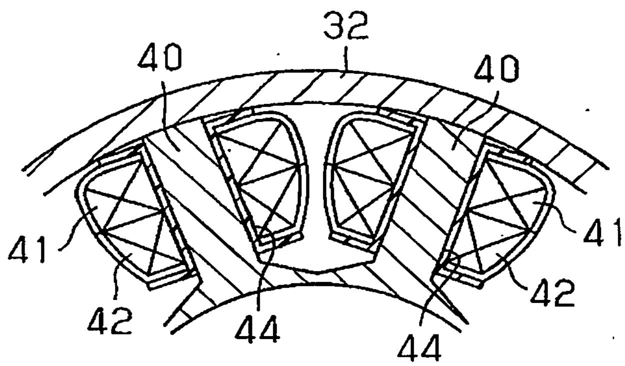


[Fig. 2]

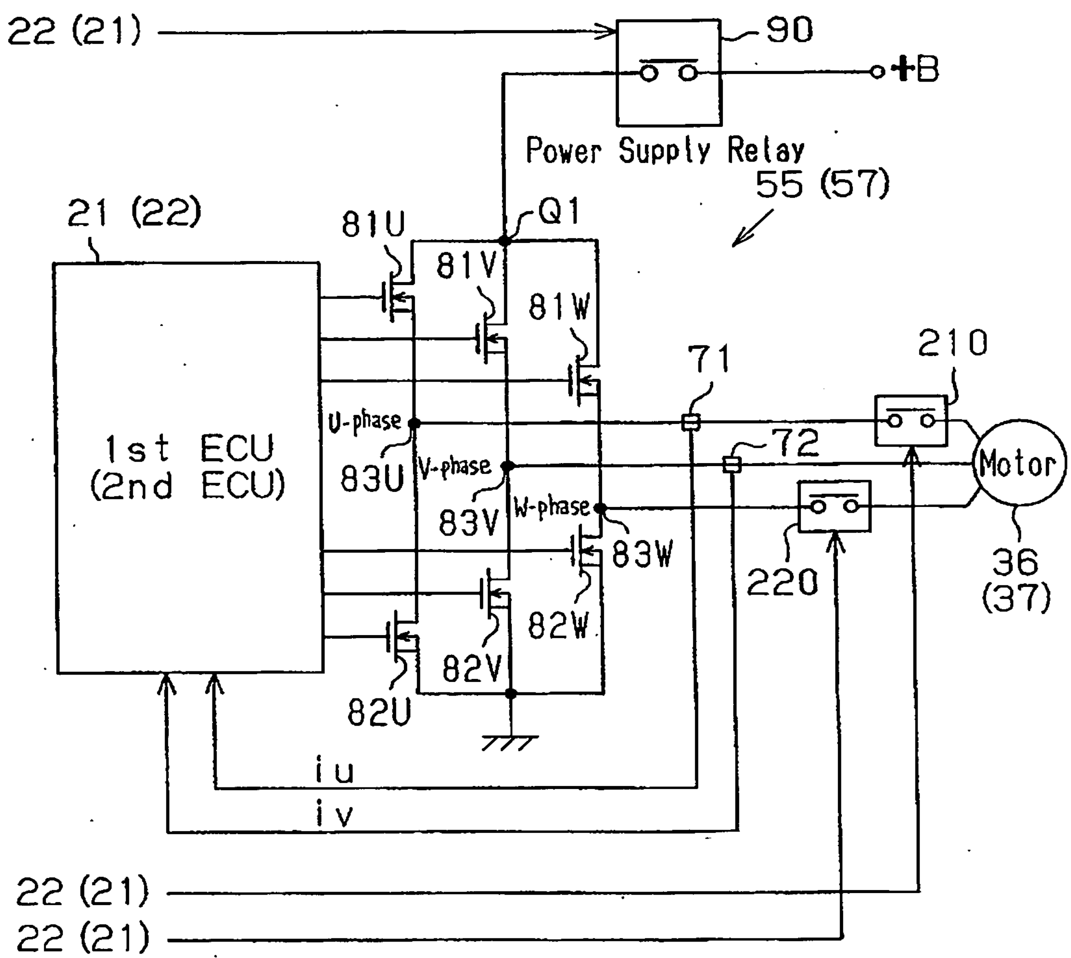


200
30
33
45
53
52
42
41
51
39
40
48
38
36, 37
32
42
41
49
51
46
47
50
34
31
35
51

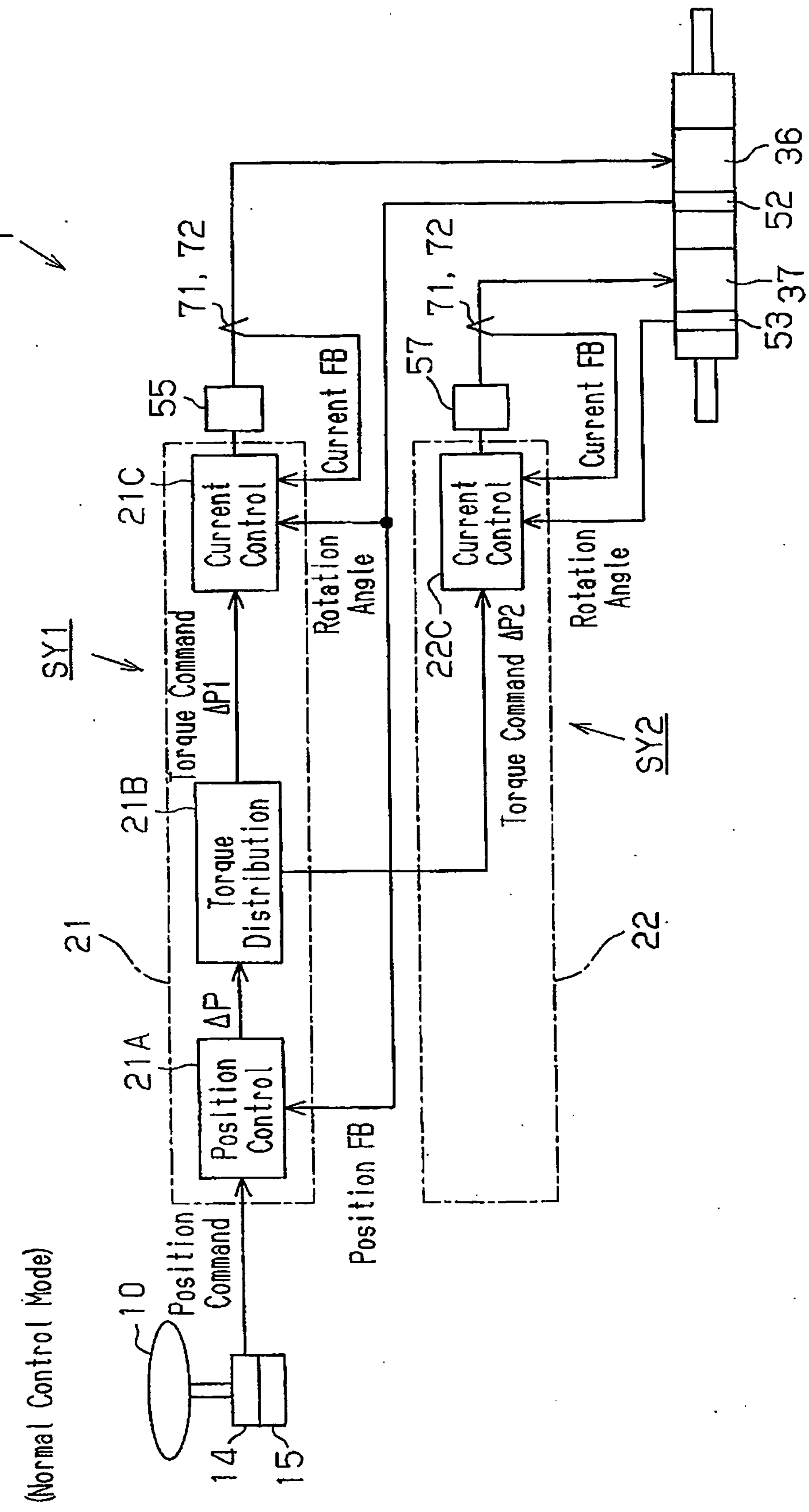
[Fig.3]


32
40
40
41
41
42
42
44
44

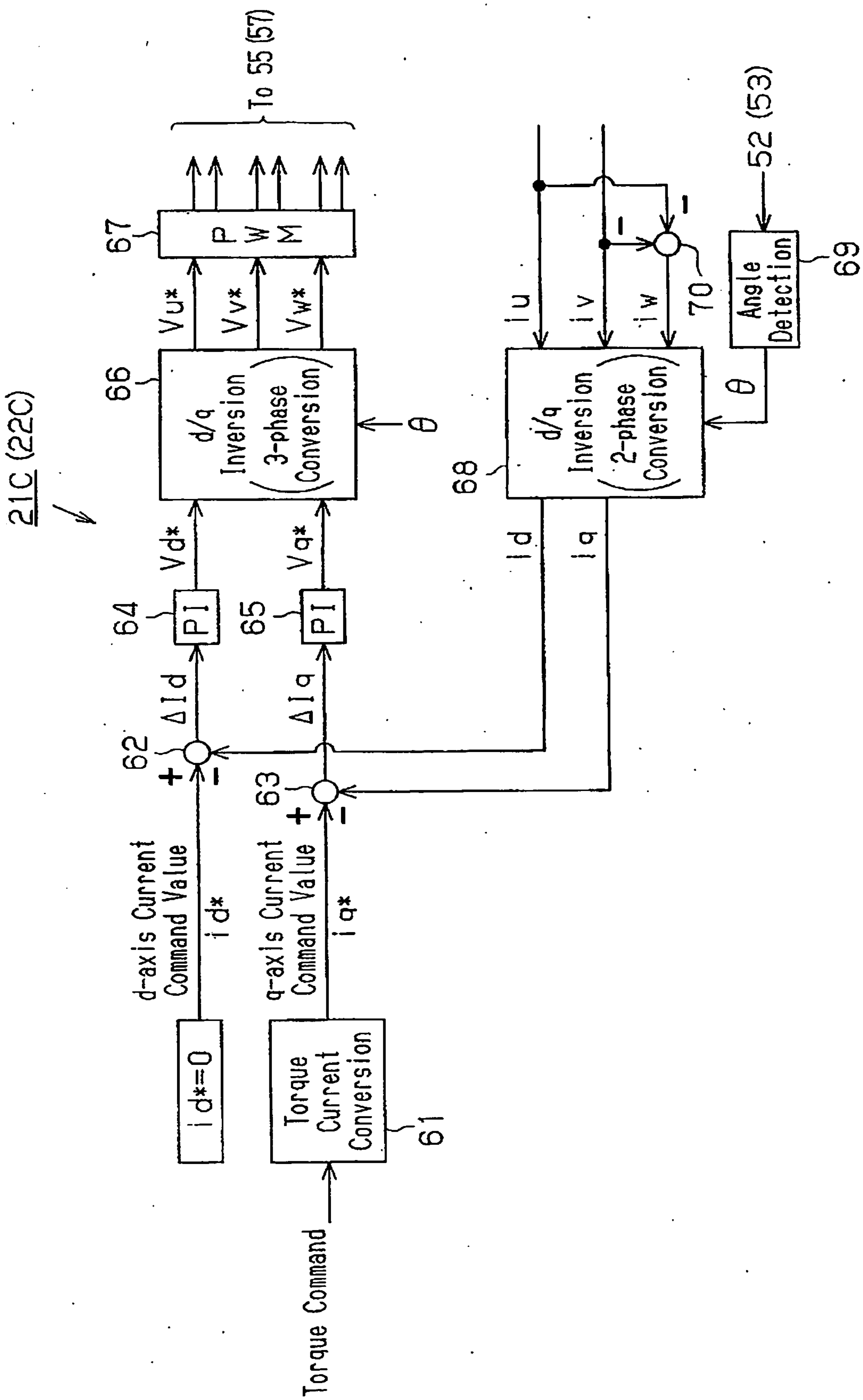
[Fig.4]


22 (21)
90
+B
Power Supply Relay
55 (57)
21 (22)
Q1
81U
81V
81W
71
210
1st ECU
(2nd ECU)
U-phase
83U
V-phase
72
Motor
83V
W-phase
83W
220
36
(37)
82W
82V
82U
iu
iv
22 (21)
22 (21)

[Fig.5]

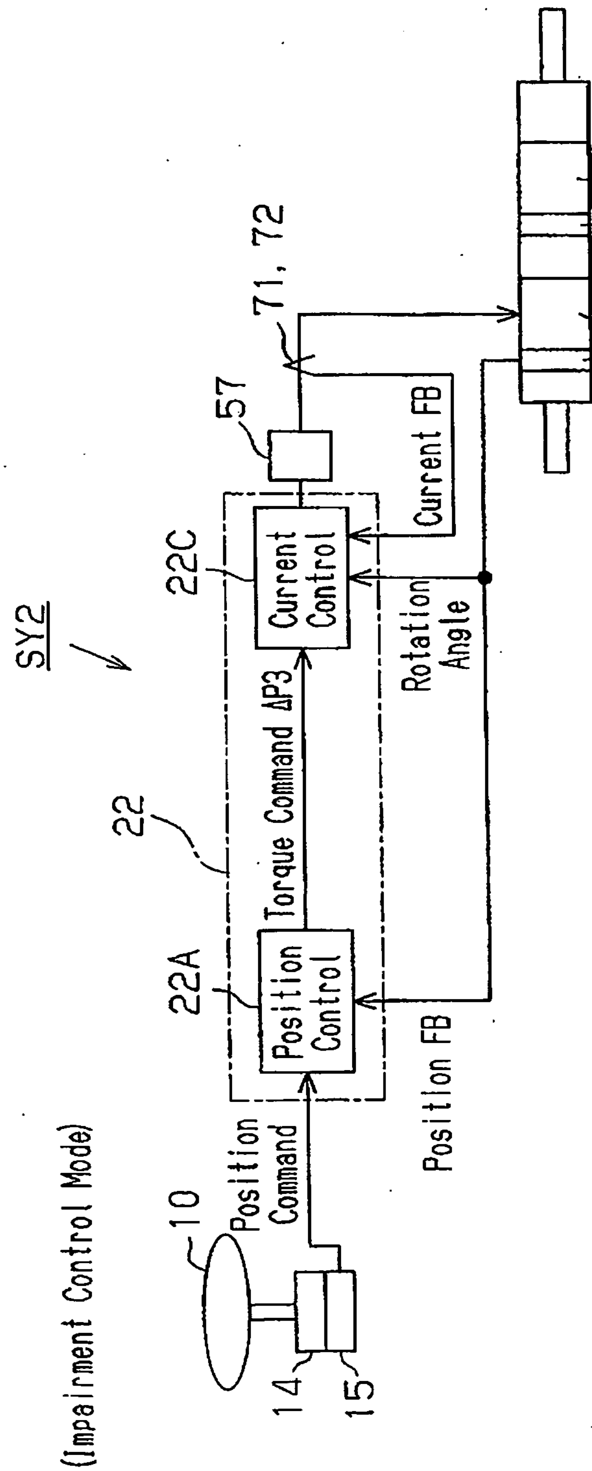

(Normal Control Mode)
1
10
14
15
Position Command
Position Control
21A
ΔP
Torque Distribution
21B
Torque Command ΔP1
Current Control
21C
21
SY1
55
71, 72
Current FB
Rotation Angle
Position FB
36
52
37
53
57
71, 72
Current FB
Current Control
22C
Torque Command ΔP2
Rotation Angle
SY2
22

[Fig. 6]

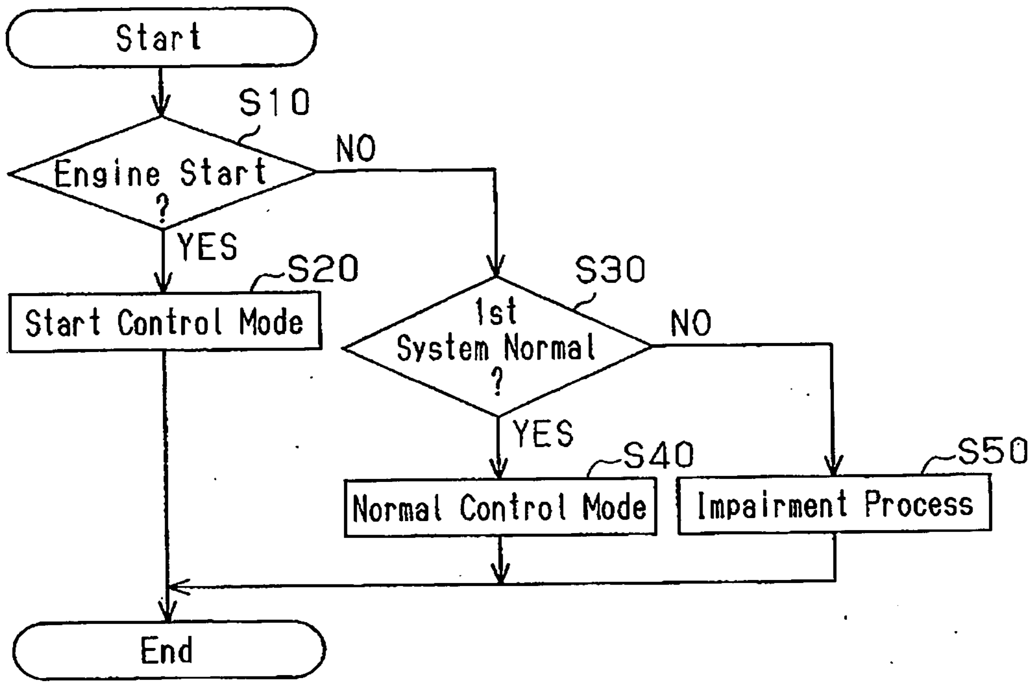


21C (22C)
Torque Command
Torque Current Conversion
61
id*=0
d-axis Current Command Value
id*
q-axis Current Command Value
iq*
62
63
+
−
ΔId
ΔIq
64
65
PI
PI
Vd*
Vq*
66
d/q Inversion (3-phase Conversion)
θ
Vu*
Vv*
Vw*
67
PWM
To 55 (57)
68
d/q Inversion (2-phase Conversion)
Id
Iq
Iu
Iv
Iw
70
69
Angle Detection
52 (53)

[Fig.7]

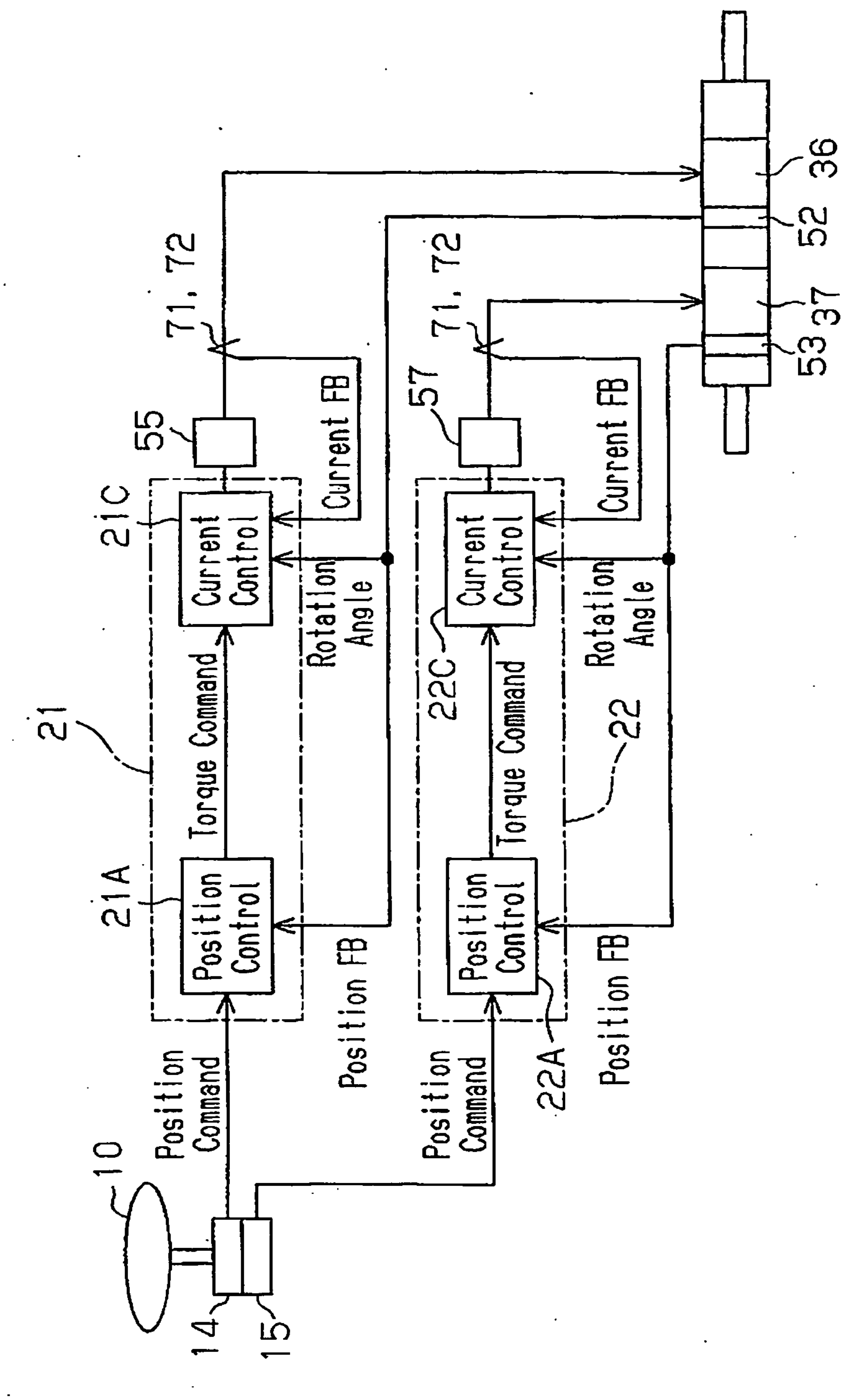

(Impairment Control Mode)
SY2
10
14
15
Position Command
22
22A
Position Control
Torque Command ΔP3
22C
Current Control
57
71, 72
Current FB
Rotation Angle
Position FB
36
52
37
53

[Fig.8]



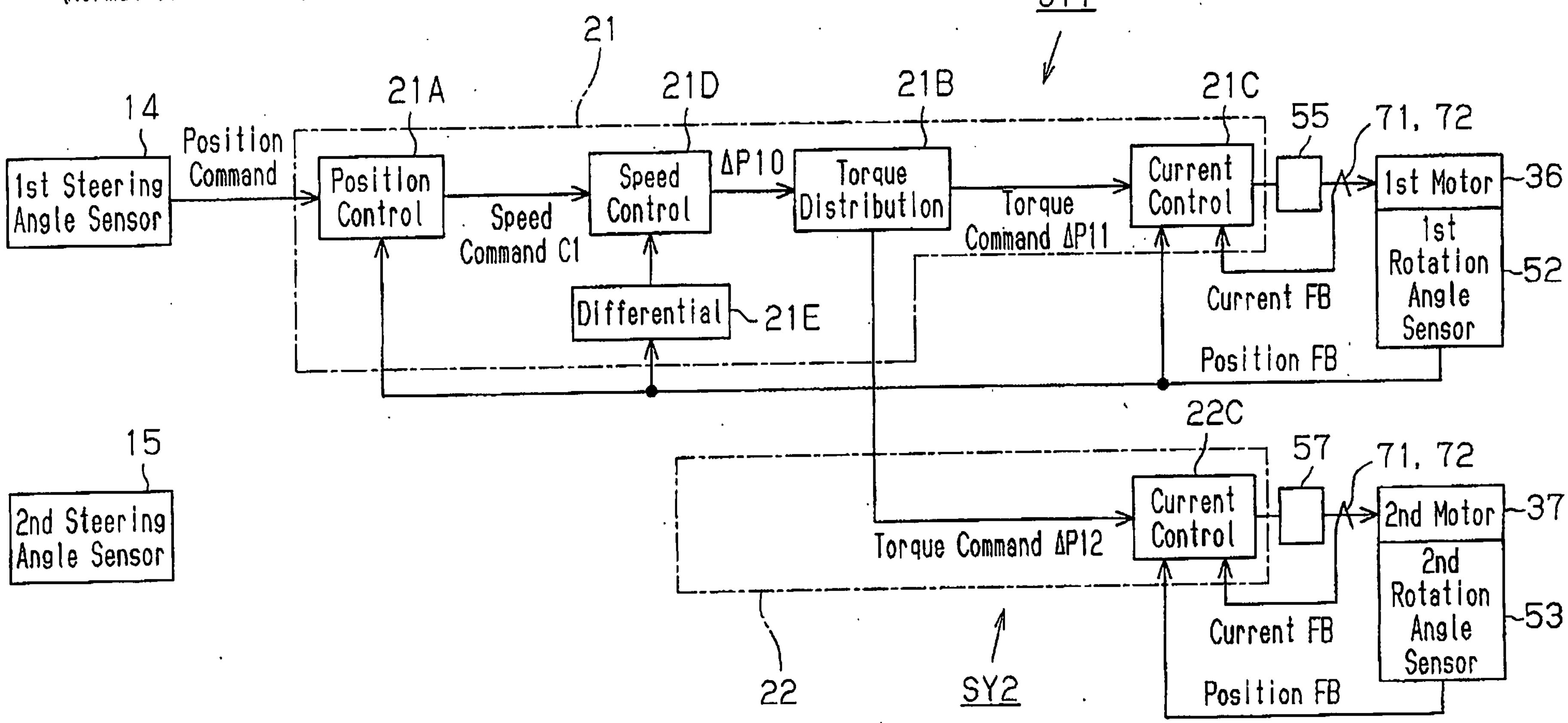
Start
S10
Engine Start ?
NO
YES
S20
Start Control Mode
S30
1st System Normal ?
NO
YES
S40
S50
Normal Control Mode
Impairment Process
End

[Fig. 9]

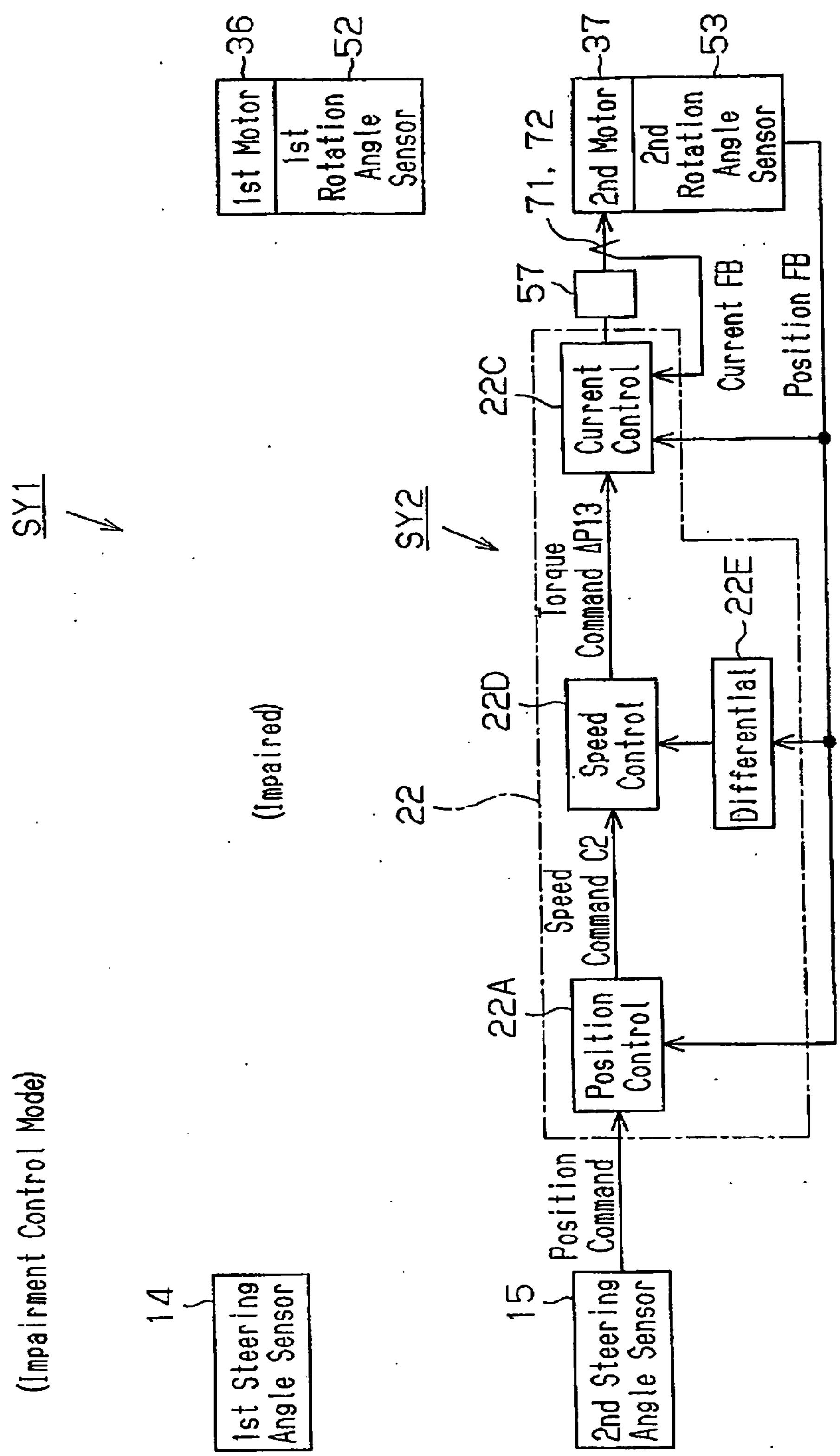

10
14
15
Position Command
Position Control
21A
21
Torque Command
Current Control
21C
55
71, 72
Current FB
Rotation Angle
Position FB
Position Command
Position Control
22A
22
Torque Command
Current Control
22C
57
71, 72
Current FB
Rotation Angle
Position FB
36
52
37
53

[Fig.10]

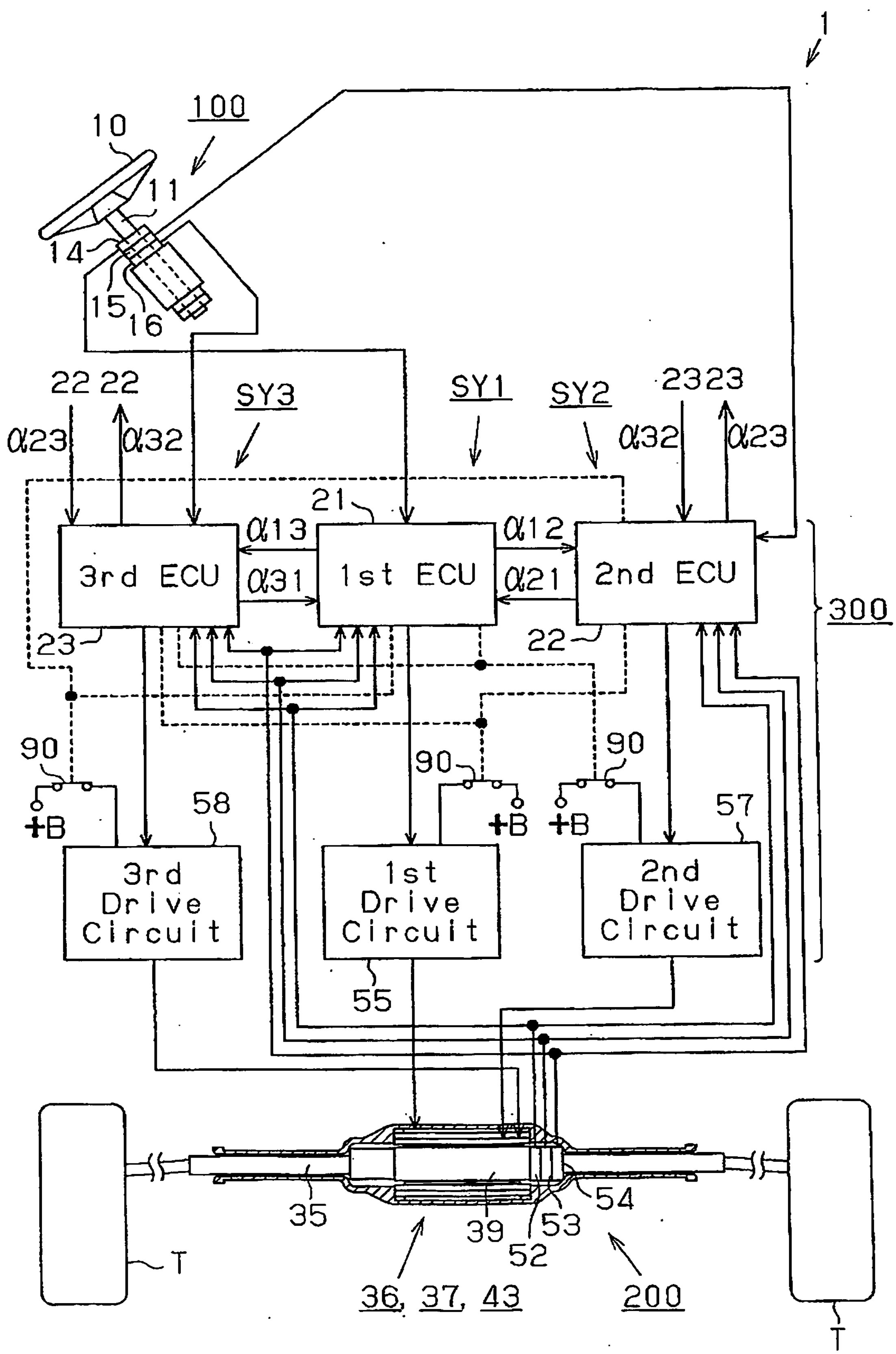
(Normal Control Mode)



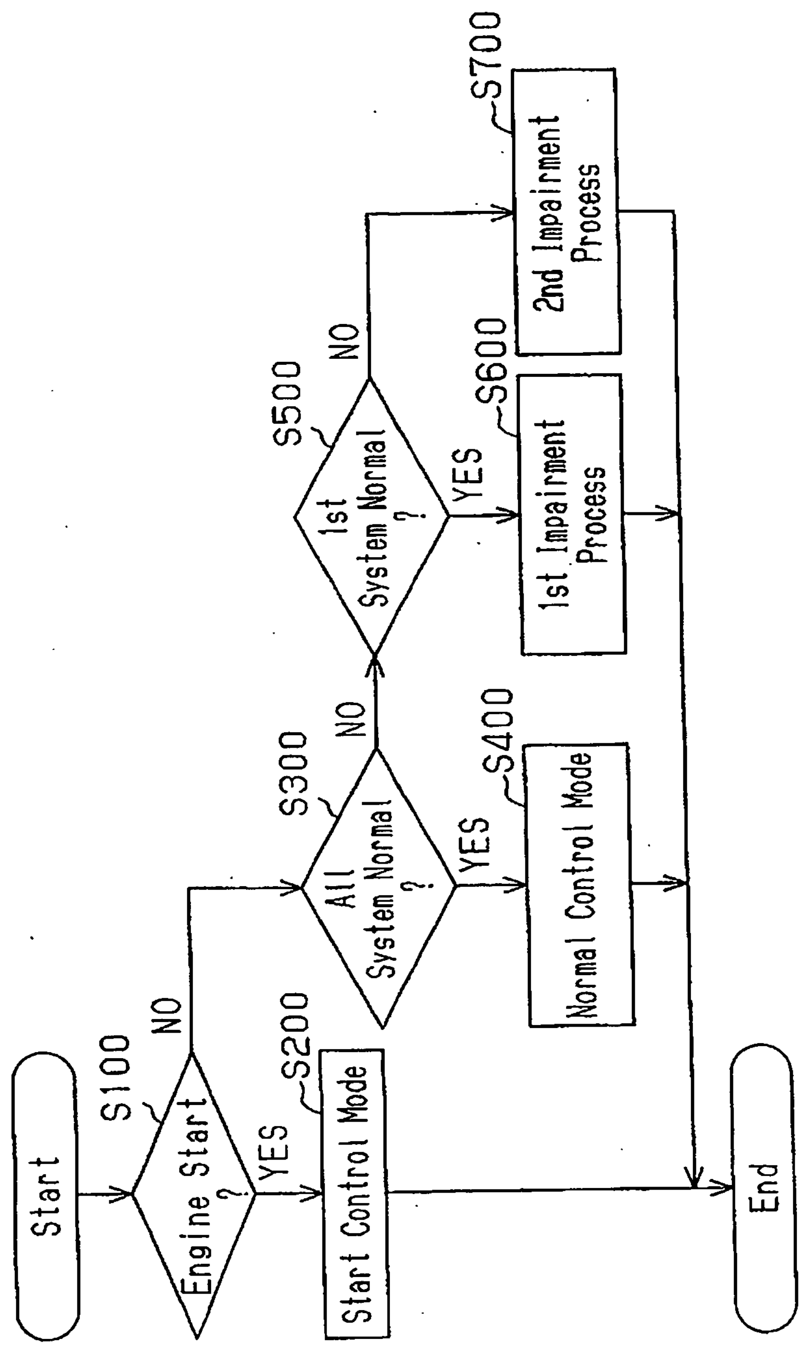
[Fig.11]


(Impairment Control Mode)
14
1st Steering Angle Sensor
SY1
(Impaired)
36
52
1st Motor
1st Rotation Angle Sensor
15
2nd Steering Angle Sensor
Position Command
22A
Position Control
Speed Command C2
22
22D
Speed Control
Torque Command ΔP13
22E
Differential
SY2
22C
Current Control
57
71, 72
Current FB
Position FB
37
53
2nd Motor
2nd Rotation Angle Sensor

[Fig.12]

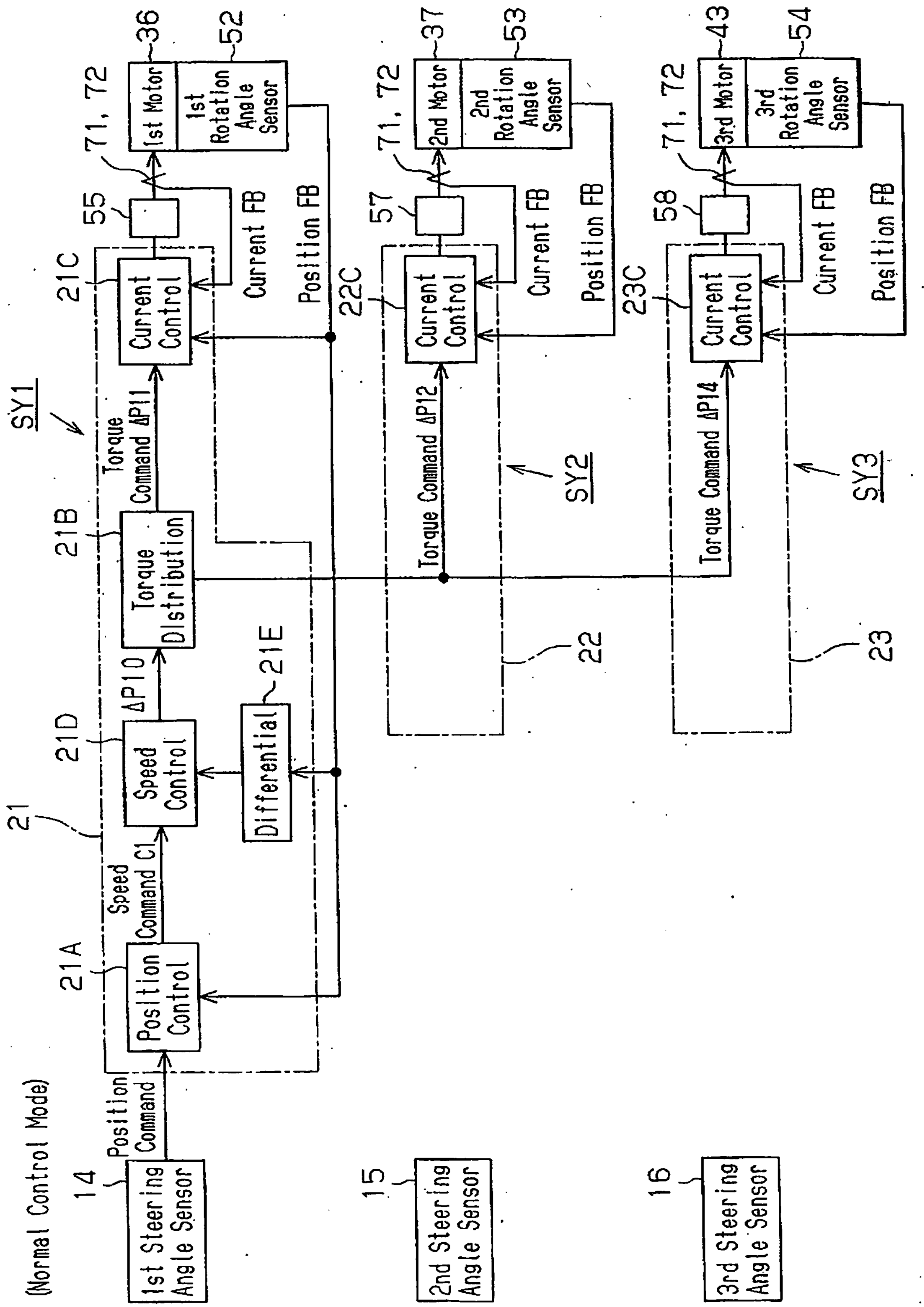

1
100
10
11
14
15
16
22 22
α23
α32
SY3
SY1
SY2
2323
α32
α23
21
α13
α12
3rd ECU
1st ECU
2nd ECU
α31
α21
300
23
22
90
90
90
+B
+B
+B
58
57
3rd Drive Circuit
1st Drive Circuit
2nd Drive Circuit
55
35
39
54
53
52
T
T
36, 37, 43
200

[Fig. 13]

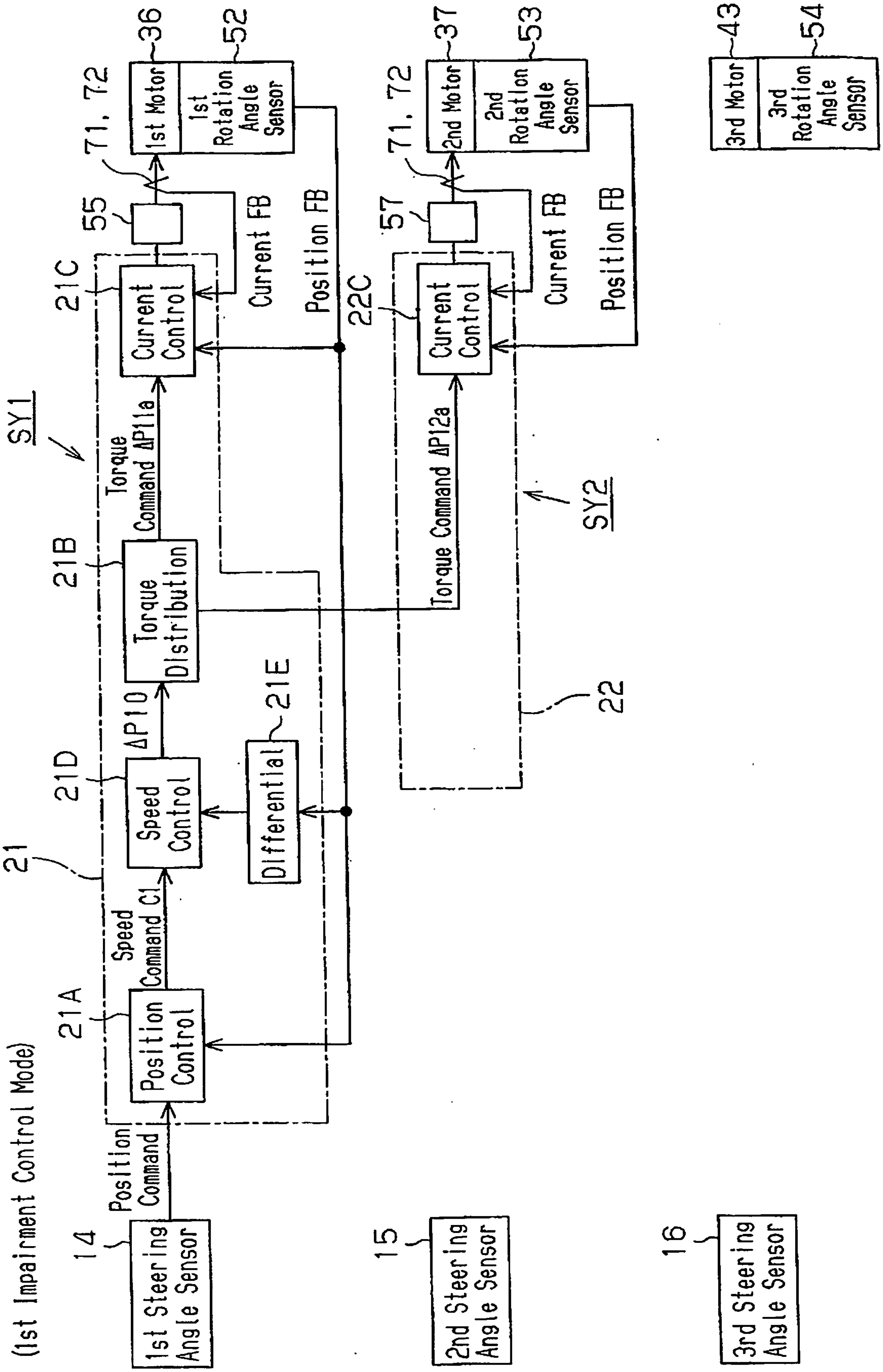


Start
S100
Engine Start ?
YES
NO
S200
Start Control Mode
S300
All System Normal ?
YES
NO
S400
Normal Control Mode
S500
1st System Normal ?
YES
NO
S600
1st Impairment Process
S700
2nd Impairment Process
End

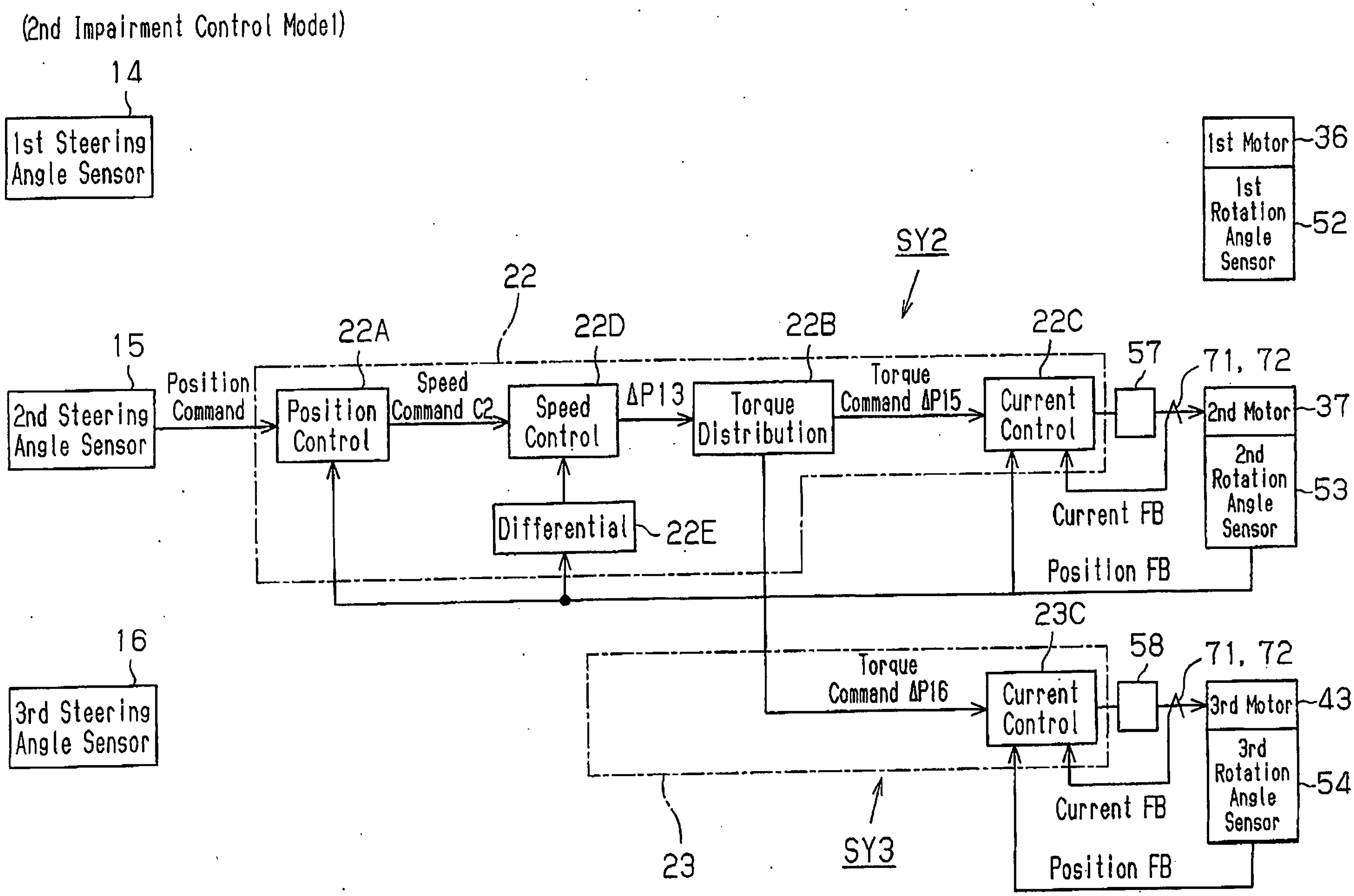
[Fig. 14]


(Normal Control Mode)
14
1st Steering Angle Sensor
Position Command
21A
Position Control
Speed Command C1
21
21D
Speed Control
ΔP10
21E
Differential
21B
Torque Distribution
Torque Command ΔP11
SY1
21C
Current Control
55
71, 72
36
1st Motor
52
1st Rotation Angle Sensor
Current FB
Position FB
15
2nd Steering Angle Sensor
22
Torque Command ΔP12
SY2
22C
Current Control
57
71, 72
37
2nd Motor
53
2nd Rotation Angle Sensor
Current FB
Position FB
16
3rd Steering Angle Sensor
23
Torque Command ΔP14
SY3
23C
Current Control
58
71, 72
43
3rd Motor
54
3rd Rotation Angle Sensor
Current FB
Position FB

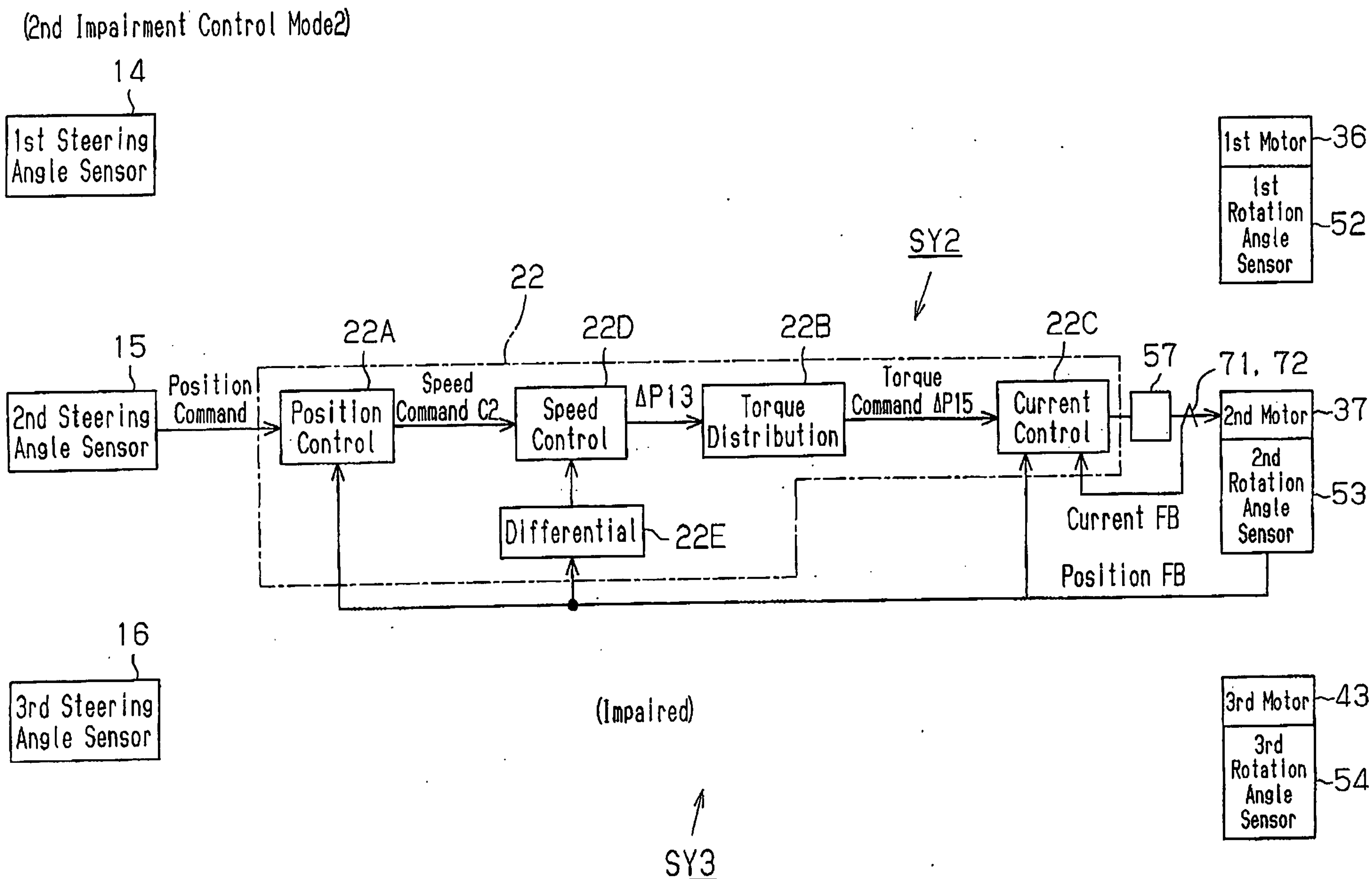
[Fig. 15]


(1st Impairment Control Mode)
SY1
SY2
21
22
1st Steering Angle Sensor
14
2nd Steering Angle Sensor
15
3rd Steering Angle Sensor
16
Position Command
Position Control
21A
Speed Command C1
Speed Control
21D
ΔP10
Differential
21E
Torque Distribution
21B
Torque Command ΔP11a
Current Control
21C
Torque Command ΔP12a
Current Control
22C
55
57
71, 72
1st Motor
36
1st Rotation Angle Sensor
52
2nd Motor
37
2nd Rotation Angle Sensor
53
3rd Motor
43
3rd Rotation Angle Sensor
54
Current FB
Position FB

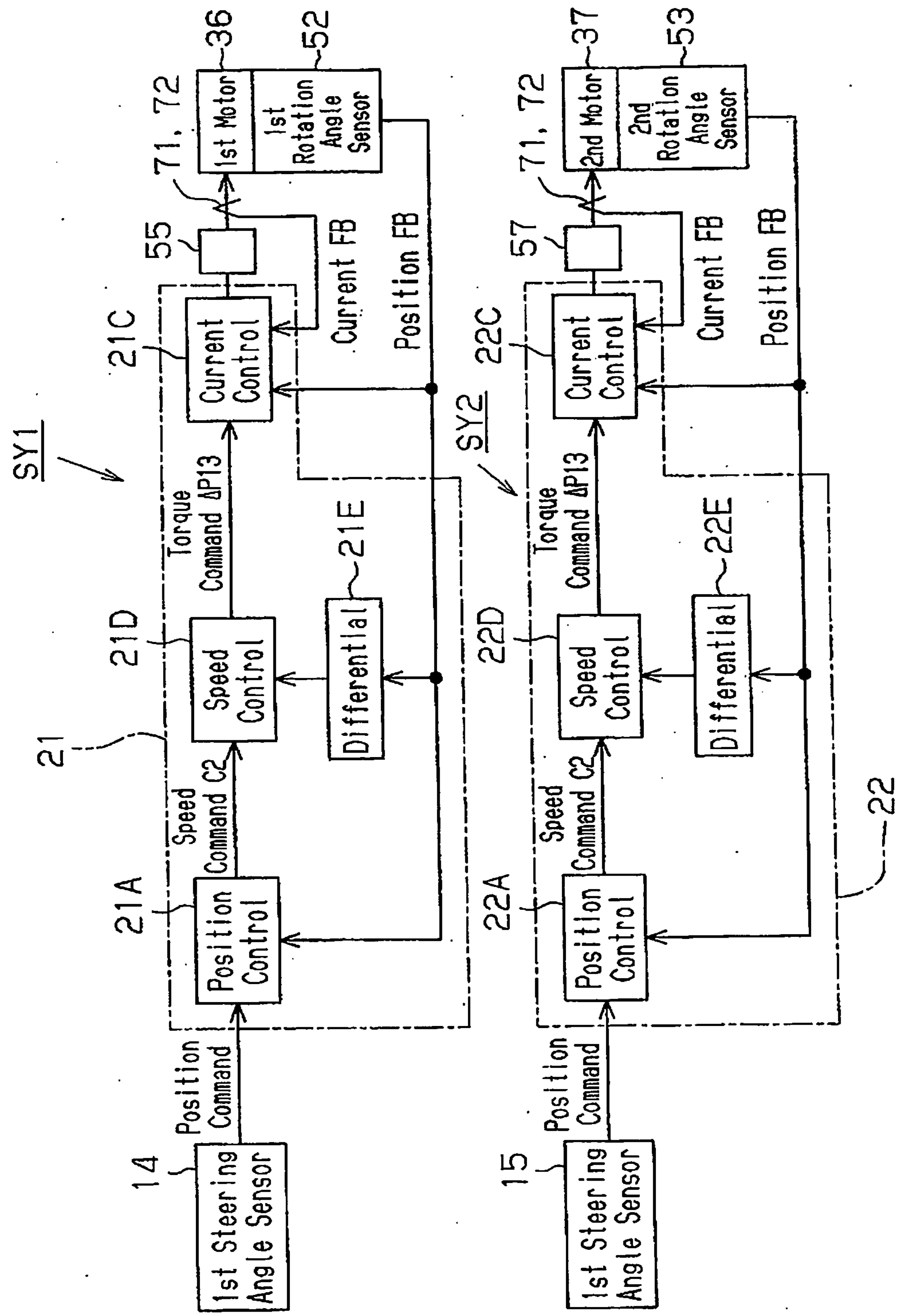
[Fig.16]


(2nd Impairment Control Model)
14
1st Steering Angle Sensor
15
2nd Steering Angle Sensor
16
3rd Steering Angle Sensor
Position Command
22
22A
Position Control
Speed Command C2
22D
Speed Control
ΔP13
22B
Torque Distribution
Torque Command ΔP15
22C
Current Control
Differential
22E
SY2
57
71, 72
1st Motor
36
1st Rotation Angle Sensor
52
2nd Motor
37
2nd Rotation Angle Sensor
53
Current FB
Position FB
23C
Torque Command ΔP16
Current Control
58
71, 72
3rd Motor
43
3rd Rotation Angle Sensor
54
Current FB
Position FB
23
SY3

[Fig.17]


(2nd Impairment Control Mode2)
14
1st Steering Angle Sensor
15
2nd Steering Angle Sensor
16
3rd Steering Angle Sensor
Position Command
22
22A
Position Control
Speed Command C2
22D
Speed Control
ΔP13
22B
Torque Distribution
Torque Command ΔP15
22C
Current Control
57
71, 72
Differential
22E
Current FB
Position FB
SY2
SY3
(Impaired)
1st Motor
36
1st Rotation Angle Sensor
52
2nd Motor
37
2nd Rotation Angle Sensor
53
3rd Motor
43
3rd Rotation Angle Sensor
54

[Fig. 18]



SY1
SY2
21
22
14
15
1st Steering Angle Sensor
1st Steering Angle Sensor
Position Command
Position Command
21A
22A
Position Control
Position Control
Speed Command C2
Speed Command C2
21D
22D
Speed Control
Speed Control
21E
22E
Differential
Differential
Torque Command ΔP13
Torque Command ΔP13
21C
22C
Current Control
Current Control
55
57
71, 72
71, 72
36
37
1st Motor
2nd Motor
52
53
1st Rotation Angle Sensor
2nd Rotation Angle Sensor
Current FB
Current FB
Position FB
Position FB

2002-349893

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[To] The Commissioner of the Patent Office

[International Patent Classification] B62D 6/00

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[Registration Number] 000003470

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[ID Number] 100105957

[Patent Attorney]

[Name] Makoto ONDA

[Amount of Charge]

[Receipt Number for Advance Payment] 002956

[Amount of Payment] 21,000 Yen

[List of Documents Attached]

[Name of Document] Specification 1

[Name of Document] Drawings 1

[Name of Document] Abstract 1

[Number of General Power of Attorney] 9720003

[Official Confirmation Required/Not Required] Required